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Levels-of-Growing-Stock Cooperative Study in Douglas-Fir:

Report No. 10—The Hoskins Study, 1963-83

David D. Marshall, John F. Bell, John C. Tappeiner

Levels-of-growing-stock study treatment schedule, showing percentage of gross basal area increment of control plot to be retained in growing stock

	Treatment							
Thinning	1	2	3	4	5	6	7	8
	Percent							
First	10	10	30	30	50	50	70	70
Second	10	20	30	40	50	40	70	60
Third	10	30	30	50	50	30	70	50
Fourth	10	40	30	60	50	20	70	40
Fifth	10	50	30	70	50	10	70	30

Background

Public and private agencies are cooperating in a study of eight thinning regimes in young Douglas-fir stands. Regimes differ in the amount of basal area allowed to accrue in growing stock at each successive thinning. All regimes start with a common level-of-growing-stock established by a conditioning thinning.

Thinning intervals is controlled by height growth of crop trees, and a single type of thinning is prescribed.

Nine study areas, each involving three completely random replications of each thinning regime and an unthinned control, have been established in western Oregon and Washington, U.S.A., and on Vancouver Island, British Columbia, Canada. Site quality of these areas varies from I through IV.

This is a progress report on this cooperative study.

Levels-of-Growing-Stock Cooperative Studies in Douglas-Fir:

Report No. 10—The Hoskins Study, 1963-83

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Abstract

Marshall, David D.; Bell, John F.; Tappeiner, John C. 1992. Levels-of-growing-stock cooperative study in Douglas-fir: report No. 10—the Hoskins study, 1963-83. Res. Pap. PNW-RP-448. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 65 p.

Results of the Hoskins LOGS study in western Oregon are summarized and management implications discussed through the fifth and final planned treatment period. To age 40 thinnings in this low site I Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stand resulted in large increases in diameter growth with reductions in basal area and volume growth and yield. Growth was strongly related to the level of growing stock. Culmination of cubic-foot mean annual increment does not appear to be near for any of the treatments.

Keywords: Growing stock (-increment/yield, increment) growing stock management, stand density, thinnings, Douglas-fir, *Pseudotsuga menziesii,* western Oregon, Oregon, series—Douglas-fir LOGS.

Summary

Results of the Hoskins LOGS study in western Oregon are summarized and management implications discussed through the fifth and final planned treatment period and the last remeasurement under the original experimental design. A calibration thinning at age 20 in this low site I Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stand resulted in an immediate and considerable increase in diameter growth. Selection of crop trees at this age seems difficult because of shifts in tree vigor and position, especially with strict spacing requirements. Through age 40, diameter growth has remained strong on the thinned plots. Total volume and basal area growth have been reduced in comparison to the unthinned plots. Merchantable cubic- and board-foot volume production on the lighter thinning treatments exceed the unthinned plots. Growth continues to be strongly related to growing stock levels; mortality has been negligible in the thinned plots. Management must consider the tradeoffs between increases in diameter growth and decreases in volume growth that are the result of reduced levels of growing stock from thinning. At age 40, the periodic annual increment for total cubic-foot volume ranges from 1.6 to over 2.2 times the mean annual increment, thereby suggesting that these plots are still far from culmination of mean annual increment.

Other LOGS (Levels-Of-Growing-Stock) Reports

Williamson, Richard L.; Staebler, George R. 1965. A cooperative level-of-growing-stock study in Douglas-fir. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.

Describes purpose and scope of a cooperative study that is investigating the relative merits of eight different thinning regimes. Main features of six study areas installed sine 1961 in young stands are also summarized.

Williamson, Richard L.; Staebler, George R. 1971. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 1—description of study and existing study areas. Res. Pap. PNW-111. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.

Thinning regimes in young Douglas-fir stands are described. Some characteristics of individual study areas established by cooperating public and private agencies are discussed.

Bell, John F.; Berg, Alan B. 1972. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 2—the Hoskins study, 1963-1970. Res. Pap. PNW-130. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 19 p.
A calibration thinning and the first treatment thinning in a 20-year-old Douglas-fir stand at Hoskins, Oregon, are described. Data tabulated for the first 7 years of management show that growth changes in the thinned stands were greater than anticipated.

Diggle, P.K. 1972. The levels-of-growing-stock cooperative study in Douglas-fir in British Columbia (report no. 3, cooperative L.O.G.S. study series). Inf. Rep. BC-X-66. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre. 46 p.

Williamson, Richard L. 1976. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 4—Rocky Brook, Stampede Creek, and Iron Creek. Res. Pap. PNW-210. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 39 p.
The USDA Forest Service maintains three of nine installations in a regional, cooperative study of influences of levels of growing stock (LOGS) on stand growth. The effects of calibration thinnings are described for the three areas. Results of first treatment thinning are described for one area.

Berg, Alan B.; Bell, John F. 1979. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 5—the Hoskins study, 1963-1975. Res. Pap. PNW-257. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 29 p.
The study dramatically demonstrates the capability of young Douglas-fir stands to transfer the growth from many trees to few trees. It also indicates that at least some of the treatments have the potential to equal or surpass the gross cubic-foot volume of the controls during the next treatment periods.

Arnott, J.T.; Beddows, D. 1981. Levels-of-growing stock cooperative study in Douglas-fir: report no. 7—Sayward Forest, Shawnigan Lake. Inf. Rep. BC-X-223. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre. 54 p.
Data are presented for the first 8 and 6 years at Sayward Forest and Shawnigan Lake, respectively. The effects of the calibration thinnings are described for these two installations on Vancouver Island, British Columbia. Results of the first treatment thinning at Sayward Forest for a 4-year response period also are included.

Williamson, Richard L.; Curtis, Robert O. 1984. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 7—preliminary results at the Stampede Creek LOGS study, and some comparisons with the Iron Creek and Hoskins LOGS studies. Res. Pap. PNW-323. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 42 p.
Summaries are given through the first treatment period for the Stampede Creek LOGS study in southwest Oregon. Results are compared with two more advanced LOGS studies and, in general, are similar. To age 43, thinning in this low site III Douglas-fir stand resulted in some reduction in volume growth and moderate gains in diameter growth. Growth was strongly related to level of growing stock. Desirable density levels are recommended for young Douglas-fir stands.

Curtis, Robert O.; Marshall, David D. 1986. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 8—the LOGS study: twenty-year results. Res. Pap. PNW-356. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 113 p.

Initial stand statistics for the levels-of-growing-stock installations were projected by the Douglas-fir stand simulation program (DFSIM) over the available periods of observation. Estimates were compared with observed volume and basal area growth, diameter change, and mortality. Overall agreement was reasonably good, although results indicated some biases and a need for revision of the upper density limit in the DFSIM program.

Curtis, Robert O. 1987. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 9—some comparison of DFSIM estimates with growth in the levels-of-growing-stock study. Res. Pap. PNW-RP-376. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 34 p.

Initial stand statistics for the levels-of-growing-stock study installations were projected by the Douglas-fir stand simulation program (DFSIM) over the available periods of observation. Estimates were compared with observed volume and basal area growth, diameter change, and mortality. Overall agreement was reasonably good, although results indicate some biases and a need for revision of the upper density limit in the DFSIM program.

Contents

Introduction

The levels-of-growing-stock (LOGS) cooperative studies in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) were established in 1963 to gather data on the response of young, even-aged Douglas-fir to intensive, frequent thinnings. The five cooperators are Forestry Canada, Oregon State University, USDA Forest Service, Washington State Department of Natural Resources, and the Weyerhaeuser Company. By 1972, nine studies had been established throughout Oregon, Washington, and on Vancouver Island British Columbia (fig. 1). Descriptions of the LOGS cooperative and the individual studies are presented by Williamson and Staebler (1971); progress and results through 1981 are given by Curtis and Marshall (1986).

The Hoskins LOGS study was established in 1963 by Oregon State University in western Oregon on lands owned by Starker Forests of Corvallis, Oregon. Intermediate results for this installation are reported by Bell and Berg (1972) for the calibration (1963-66) and first treatment (1966-70) periods, Berg and Bell (1979) for the second (1970-73) and third (1973-75) treatment periods, and Tappeiner and others (1982) for the fourth treatment period (1975-79). At the end of the 1983 growing season, the study completed the fifth and final treatment period of the experiment as originally designed. The purpose of this report is to (1) document information about this long-term study, (2) update results presented by Curtis and Marshall (1986) particular to the Hoskins installation, and (3) present and discuss the implications of results through the final treatment period.

Objectives

The LOGS cooperative studies evolved out of work in the late 1950s by George Staebler (1966) that stressed the undesirability of maintaining too much growing stock. Staebler suggested that by reducing the amount of growing stock through thinning the increment would be redistributed to the remaining faster growing trees and mortality would be reduced and harvestable. The objectives of the LOGS studies were "to determine how the amount of growing stock retained in repeatedly thinned stands of Douglas-fir affects cumulative wood production, tree size, and growth-growing stock ratios."[1] Treatments were designed to include a wide range in growing stock so that the results would tell "how to produce any combination of factors deemed optimum from a management standpoint" (see footnote 1). Additional information on the background and history of the cooperative can be found in Curtis and Marshall (1986) and King and others.[2]

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[1] Stabler, George R.; Williamson, Richard L. 1962. Plan for a level-of-growing-stock study in Douglas-fir. Unpublished study plan. On file with: Forestry Sciences Laboratory, 3625-93d Avenue, S.W., Olympia, WA 98502.

[2] King, James E.; Bell, John F.; Marshall, David D. Levels-of-growing stock cooperative study in Douglas-fir: the Skykomish study. Research paper in preparation.

Figure 1—Triangles indicate locations of the nine levels-of-growing-stock studies in coastal Douglas-fir. The solid triangle identifies the study area of this report.

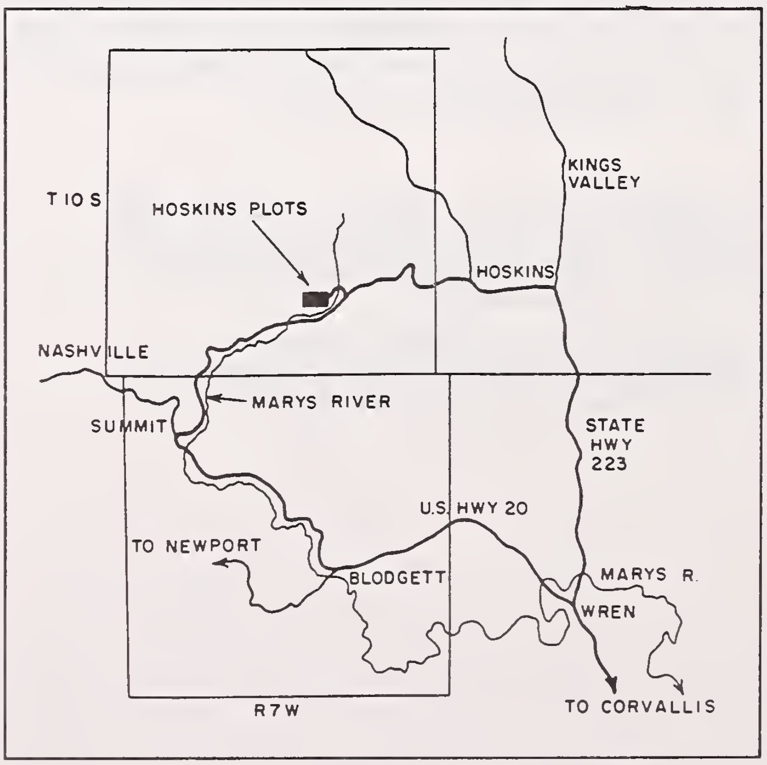

Figure 2—Location of the Hoskins study.

Methods

Description of Study Area

The study was established in a uniform, even-aged 20-year-old Douglas-fir stand that regenerated naturally after wildfire in the Oregon Coast Range. The stand is near Hoskins, about 22 miles west of Corvallis (fig. 2) in Benton County (sec. 27 of T. 10 S., R. 7 W., Willamette Meridian). The breast height age from borings on 54 trees (two per plot) during plot establishment in 1963 was 13 years. On the unthinned control plots, the number of trees initially ranged from 1,610 to 1,885 per acre, basal area from 120 to 160 square feet per acre, and the average diameter from 3.6 to 4.2 inches. Heights to live crown were uniform and near 8 feet at the time of plot establishment, and crown ratios were about 80 percent. Figure 3 shows examples of the initial (age 20) stand conditions in the control and treatments after calibration; the current (age 40) stand conditions are shown in figure 4.

Annual precipitation in the area is about 65 to 75 inches and falls primarily as rain. The temperatures average 50 °F with 160 to 190 frost-free days per year (Knezevich 1975).

The soils are described by Knezevich (1975) as deep, well-drained silty clay loams of the Apt series that formed in colluvium from mixed sedimentary and igneous rocks. The surface layer is about 10 inches thick and a very dark brown and very dark grayish-brown silty clay loam. The subsoil is dark brown, dark yellowish-brown, or strong brown silty clay and clay that is about 60 inches deep. The water-holding capacity ranges from 7 to 10 inches. Slopes range from 10 to 40 percent on a southerly aspect at an elevation of about 1,000 feet on the upper one-third of the slope.

The overstory is 100 percent Douglas-fir. Initially there was no understory vegetation in the area due to the dense overstory. This condition remains on the control plots. Some of the understory species that have developed on the thinned plots include sword-fern (*Polystichum munitum* (Kaulf.) Presl) and salal (*Gaultheria shallon* Pursh) on the lighter thinnings, ocean-spray (*Holodiscus discolor* (Pursh) Maxim) in the intermediate densities, and hazel (*Corylus cornuta var. californica* (DC.) Sharp) on the heaviest thinned plots. The climax plant association is *Tsuga/Gaultheria/Polystichum* (Franklin 1979).

The site index is 160 to 170 feet at 100 years (McArdle and others 1961) or 130 to 135 feet at 50 years (King 1966).

Experimental Design

This experiment was designed to test eight thinning regimes. The treatments associated with these regimes were prescribed to achieve a wide range in growing stock conditions. Each of the eight treatments and an unthinned control are replicated three times on 27 0.2-acre-square sample plots in a completely random design (fig. 5). The experiment consists of five periodic thinnings in each treatment. The periods between treatments are considered to be subplots for the purposes of the analysis of variance, which is a split-plot-in-time or a repeated-measures design. The experiment was designed to last for five treatment periods after an initial calibration period. The final treatment period was completed at Hoskins after the 1983 growing season.

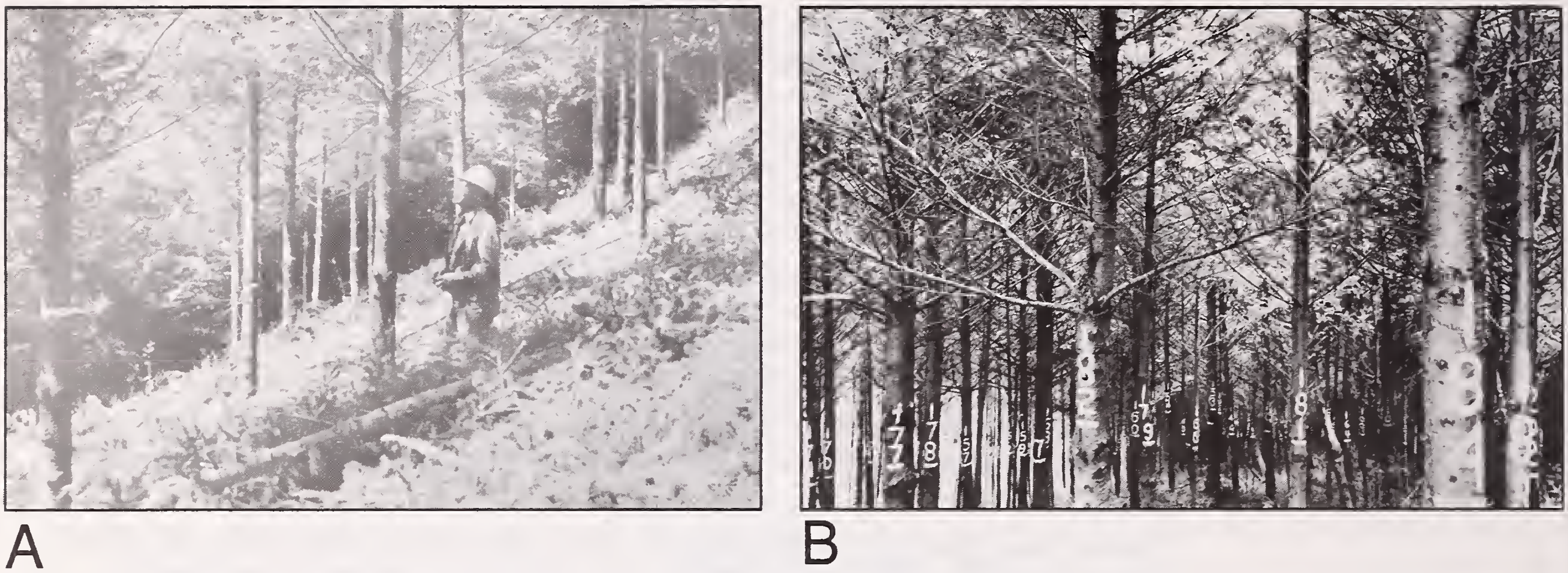

Figure 3—Hoskins study (a) after calibration cut and (b) control, 1963, age 20.

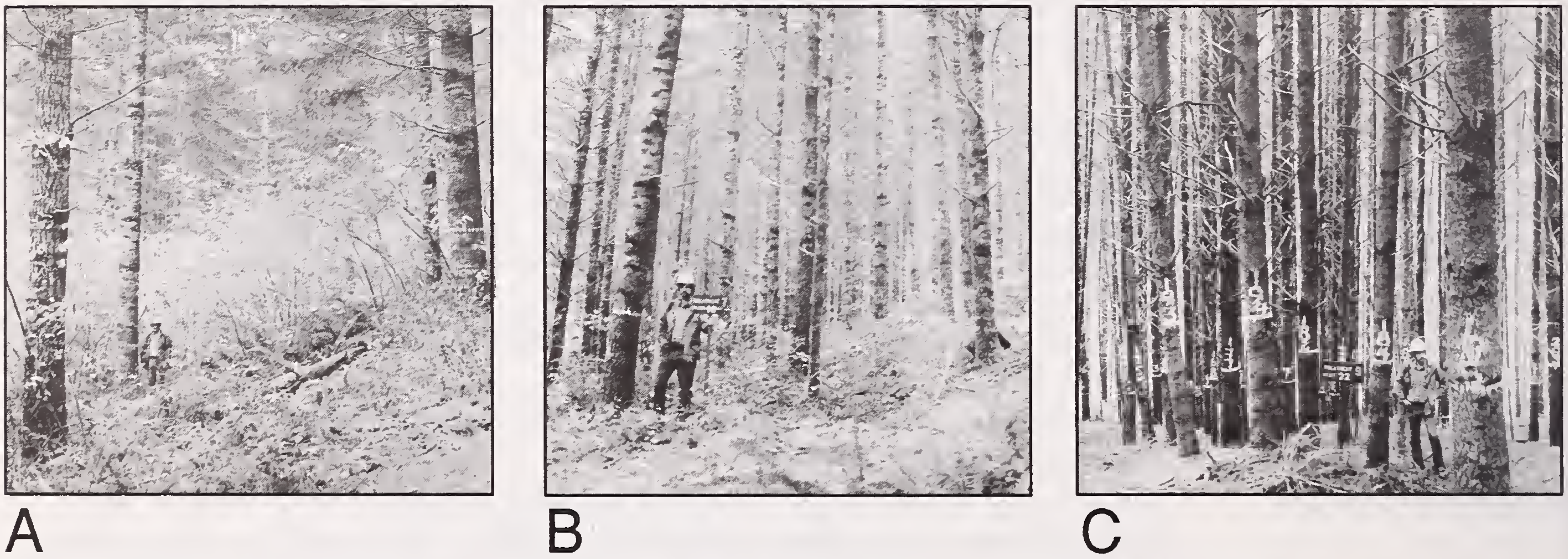

Figure 4—Hoskins study at end of the fifth treatment period 1984, age 41: (a) treatment 1; (b) treatment 7; and (c) control.

The criteria for initial stand selection were:

1. A high degree of uniformity in stocking and site quality over an area sufficient to accommodate the approximately 9-acre installation.
2. Twenty to forty feet in height.
3. Vigorous and of density such that individual tree development had not been strongly influenced by competition, as evidenced by live crown extending over most of the bole.
4. Contain at least 80 percent of the basal area in Douglas-fir.

The Hoskins installation met all these criteria, although not all the plots are contiguous. Because of space limitations, five plots had to be located on closely adjacent but similar areas (fig. 5). Buffer strips were maintained around the installation but not between plots.

Stand Treatments

The prescribed treatments were rigidly controlled to provide for compatibility among installations on different sites.

Selection of crop trees—Crop trees were selected before the initial calibration thinning at the rate of 16 per plot or 80 per acre. These trees were well-formed, vigorous dominants, with at least 13.5 feet between adjacent crop trees. Ideally, there would be four crop trees on each plot quarter. At Hoskins, crop trees were numbered 1 through 16 and painted with white to distinguish them from other trees on a plot, which were painted with other colors representing the treatment.

Of the total 384 crop trees on the treated plots, 23 (6 percent) were replaced early during the study, primarily for slow growth (one was cut after it developed a dead top). These replacements were distributed throughout the treatments. Of the replaced crop trees, two survived through the fifth treatment period, one later died (treatment 7), and the rest were cut in the period after being replaced. Where replacements were made, tree statistics were calculated with the new trees rather than the originals. During the last two treatment periods, 17 and 3 crop trees were cut in treatments 1 and 2, respectively, after all noncrop trees had been cut. In addition, a crop tree was cut from both treatments 3 and 5 for unknown reasons. In the control plots, two crop trees died during the study and one was later replaced.

Calibration thinning—All 24 plots assigned to receive thinning treatments also received a calibration or preparatory thinning. This initial thinning was intended to reduce the variation in the original stocking, thereby resulting in uniform growth potential for all treated plots.

The study plan (see footnote 1) called for the stand to be thinned to an initial spacing based on the equation:

$$S = 0.6167D +*8 ,$$

where S is the average spacing in feet and D is the quadratic mean d.b.h. (diameter at breast height) of the trees left. The calibration thinning was controlled by the specifications that the average d.b.h. of the leave trees be within ± 15 percent of the installation mean and that leave tree basal areas be within ± 3 percent of the mean, as recommended by the study plan for stands where the estimated average d.b.h. of the leave trees was greater than 4.5 inches. (Smaller stands were controlled by using number of trees instead of basal area).

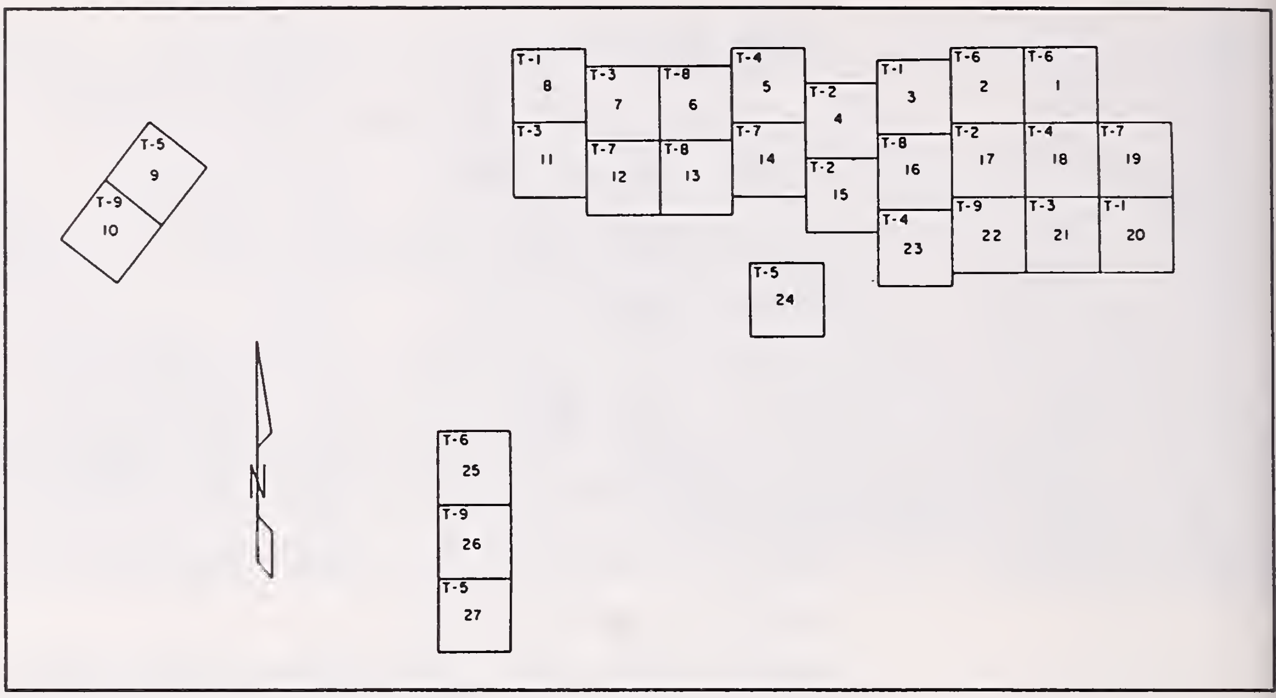

Figure 5—Layout of the Hoskins levels-of-growing-stock study. The plots are one-fifth acre.

Thinning treatments—Plots were thinned each time the crop trees grew 10 feet in height so that thinnings would be frequent when height growth and crown development were most rapid (Staebler 1960). This resulted in treatment thinnings in 1966, 1970, 1973, 1975, and 1979 at total ages of 23, 27, 30, 32, and 36 years. The 1975 treatment was premature and created some inconsistent results for that short period. The last remeasurement, at the end of the final treatment period, was in 1983 at stand age 40 years.

Thinning intensity was related to gross basal area growth on the controls and to predetermined thinning regimes (see table on inside front cover) designed to give a wide range in densities. Basal area after thinning was calculated with the following formula:

$$BA_n = BA_{n-1} + GBAG(P) ,$$

where

BA_n = basal area (ft^2/acre) retained after thinning at the beginning of a treatment period,

BA_{n-1} = basal area (ft^2/acre) at the beginning of the preceding treatment period,

GBAG = average gross basal area growth on the control plots (that is, the increase in basal area of the live trees plus the mortality during the preceding period), and

P = predetermined percentage of gross basal area growth of the controls to be retained for the respective period and treatment (see table, inside front cover).

A percentage of the gross growth on the control plots was used because it is assumed that this approximates full production on a given site at full stocking. The expected trends in residual basal area created by the eight treatments are shown in figure 6.

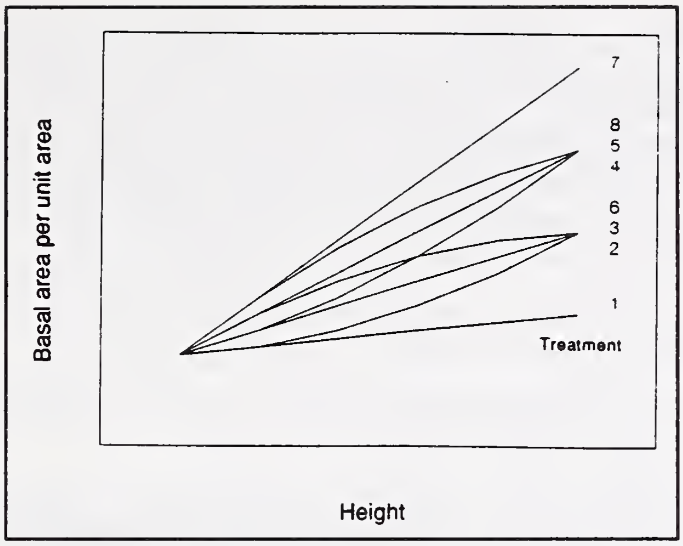

Figure 6—Levels-of-growing-stock study in Douglas-fir idealized trends of basal area for the eight thinning regimes.

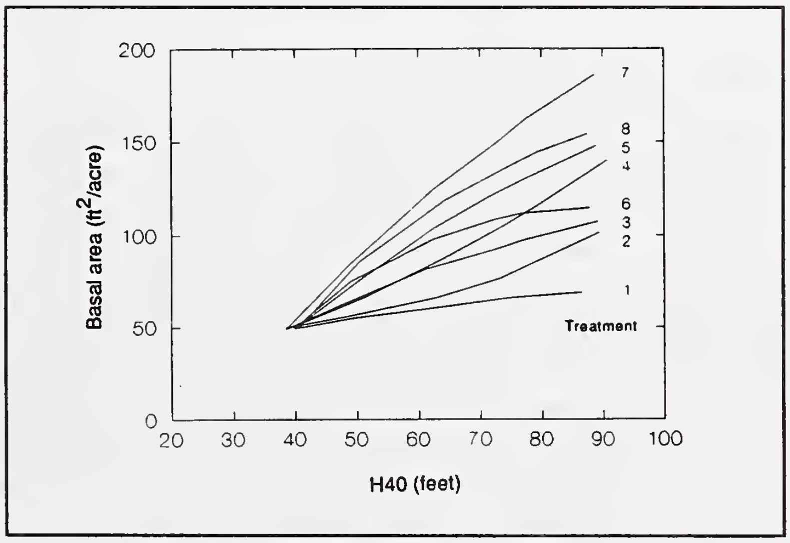

Figure 7—Residual (after treatment) stand basal area at the start of each period for the eight thinning regimes.

The eight treatments all accumulate growing stock throughout the experiment (that is, all treatments increase in basal area), but at fixed, increasing, or decreasing rates (fig. 7). The four fixed-percentage treatment regimes (1, 3, 5, and 7) always retain growing stock at four constant percentages of the control plots' gross basal area growth. The levels are 10, 30, 50, and 70 percent, which represent heavy to light thinnings, respectively. The variable-percentage treatments represent two increasing- and two decreasing-percentage treatment regimes. The increasing treatments accumulate growing stock slowly at first through heavier cuts and then more rapidly with lighter subsequent thinnings. The percentages of growing stock retained progress from 10 to 50 and 30 to 70 for treatments 2 and 4, respectively. The decreasing treatments (6 and 8) are just the opposite in that they quickly accumulate growing stock through light initial thinning and then at decreasing rate through heavier cuts to give percentages progressing from 50 to 10 and 70 to 30, respectively.

Tree removal guidelines—The thinning guidelines for tree removal were:

1. No crop trees were to be cut until all noncrop trees had been cut.
2. The average diameter of the trees removed at each thinning (d) was to be equal to the average diameter of the noncrop trees before thinning (D) (that is, d/D=1.0 for the noncrop trees only). For all trees, this results in a d/D ratio of less than 1, which approximates a crown type thinning.
3. Trees removed in a thinning were distributed across the entire diameter range of the trees available for cutting.

After all noncrop trees had been removed, some crop trees were removed in an attempt to achieve a d/D of 1.0.

Treatment history—The calibration thinning was a precommercial thinning and was performed as a training exercise by a State of Oregon Forestry Department emergency fire crew. The trees were felled and the crowns lopped in place. The crew used axe handles to break off all dead branches on live trees (within 5 to 6 feet of the ground) to facilitate marking. During the five treatment thinnings, trees were bucked and unmerchantable material and tops were left on the plots. Merchantable logs were removed by horse and tractor (winching to skid trails) for the land owner. Logging damage was minimal.

Data Collection and Summarization

All trees with a d.b.h. of 1.6 inches or more were numbered with paint during the initial calibration thinning. The d.b.h. point was permanently marked with a painted ring. A different color was used for each treatment. At each measurement, the d.b.h. of all live trees was measured to the nearest 0.1 inch. In addition, 12 to 15 trees on each plot were measured for total height to develop local volume equations. These trees were distributed through the range of diameters, with two-thirds of the sample trees larger than the stand quadratic mean d.b.h. Height-sample trees that died or were cut were replaced with trees of similar size. Heights to live crown were measured on the height-sample trees in 1983. The initial measurements were made after the end of the 1963 growing season. All subsequent remeasurements and thinnings were made during the dormant period after the growing season.

Total volume, inside bark, was calculated for each sample tree with measured heights by using the Bruce and DeMars (1974) equation for cubic-foot volume (CVTS). Volumes for all trees on each plot were calculated by using local volume equations of the form:

$$\ln(CVTS) = a + b*\ln(dbh) ,$$

where ln is the natural logarithm and a and b the regression coefficients fit by using the sample trees from each plot. Individual-tree Scribner board-foot volume was calculated by using the tarif system (Chambers and Foltz 1979), d.b.h., and calculated CVTS. Plot volumes were calculated by summing the individual tree volumes. The tree heights measured on plot 10 in 1975 were consistently low as a result of apparent measurement errors. Individual trees were adjusted by using the previous and later measurements to fit the equation:

$$ht = a + b*age + c*age^2 ,$$

where age is the stand age at each measurement.

Net periodic growth was calculated as the difference between the live stand at the start and at the end of the growth period. The gross periodic growth in basal area and volume is the net growth plus the mortality occurring during that period. Net diameter growth is strongly influenced by mortality and may not be clearly interpretable as a response to thinning. For this reason, survivor growth, which represents the growth of only the trees alive at the end of the period, also is used (Curtis and Marshall 1986).

Growth percentages (growth as a percentage of the mean period growing stock, X) were calculated as:

$$\frac{100(\text{period increment of X})}{(X_1 + X_2)/2},$$

where X_1 and X_2 are the values of the live growing stock variable at the start and end, respectively, of the growth period.

Stand height is presented as the average height of the 40 largest trees per acre (H40) by d.b.h. for a given plot. This was calculated by:

1. Calculating the quadratic mean d.b.h. of the eight largest trees per plot (largest 40 per acre).
2. Calculating the corresponding average tree volume by using the plot local-volume equation for the specific plot and measurement.
3. Calculating H40 by substituting the mean volume and diameter of the largest eight trees per plot into the Bruce and DeMars (1974) volume equation and solving for tree height.

This procedure gave estimates close to those from height-diameter equations but avoided problems in modifying existing LOGS summary programs. (See Curtis and Marshall [1986] for further details.)

Results

Calibration Thinning

The calibration, or preparatory treatment, was a very carefully controlled precommercial-type thinning that left uniform conditions in the 24 thinned plots. The three unthinned control plots were used to estimate the initial conditions before thinning. An estimated 1,384 trees per acre and 88.3 square feet of basal area were removed from the treated plots. The approximate d/D ratio was 0.90. The quadratic mean d.b.h. increased from 3.8 to 5.2 inches as a result of the thinning and an estimated 1,238 cubic feet per acre was removed. The stand tables (table 16) suggest that some of the larger trees may have been removed during the calibration thinning. The initial conditions after the calibration cut are given in table 1.

Table 1—Stand statistics for the 3 control and 24 treatment plots after the calibration thinning[a]

Plots	Number of trees per acre	Quadratic mean d.b.h.	Basal area	Total volume	Height of 40 largest
		Inches	*Ft^2/acre*	*Ft^3/acre*	*Feet*
Controls	1726.7 (142.2)	3.8 (0.3)	138.1 (18.5)	1982.3 (313.9)	42.7 (1.9)
Treated	342.7 (28.4)	5.2 (0.2)	49.8 (0.9)	743.8 (31.4)	39.5 (1.6)

[a] Standard deviations are given in parentheses.

Table 2—Periodic net growth in basal area and volume during the calibration period (3 years)

Stand condition	Basal area	Volume
	Ft^2	*Ft^3*
Thinned Plots (n=24):		
Mean—	12.3	284.9
SD[a]	.5	15.8
CV[b]	4.0 percent	5.5 percent
Unthinned Plots (n=3):		
Mean—	16.2	468.7
SD[a]	1.2	28.2
CV[b]	7.5 percent	6.0 percent

[a] SD=standard deviation.
[b] CV=coefficient of variation.

During the 3-year calibration period, the variation in basal area and volume growth was low on the control plots. Variation in basal area growth was greatly reduced by the calibration treatment, but the variation in volume growth was only slightly reduced (table 2) by the 64-percent reduction in growing stock. Growth during the calibration period was also lower owing to the reduction in growing stock from an average of 138.1 square feet per acre in the controls to 49.8 square feet per acre in the thinned plots. Diameter growth responded quickly, however, by more than doubling to 0.55 inch per year on the thinned plots. In contrast, net diameter growth (which includes the change in average diameter due to mortality as well as growth) was 0.25 inch per year on the controls; survivor diameter growth (growth only on trees alive at the end of the calibration period) was only 0.12 inch per year. If any large noncrop trees were removed during the calibration thinning, the total yield of the thinned plots was reduced below their potential.

Status of Crop Trees

Initially, 16 crop trees were selected per plot (80 per acre) before the calibration thinning. These trees were not necessarily the largest trees on a plot because of spacing requirements. Of the 16 actual largest trees per plot, only an average of 3.7 (23 percent) were selected as crop trees on the control plots. Due to the removal of some larger trees during the calibration thinning, the crop trees made up a greater percentage of the largest trees remaining on the thinned plots (average of 7.2 trees or 45 percent). Measurements (after calibration and final) are summarized by treatments to compare all trees, crop trees, the 80 largest d.b.h. trees, and the 40 largest d.b.h. trees per acre stand components in table 3. The average diameter for the crop trees on the treated plots was 5.8 inches at the start of the study compared to 6.7 inches for the 80 largest trees per acre; difference were slightly greater on the controls (5.6 and 6.9 inches, respectively). This crop tree selection resulted in greater growth of the 80 largest trees than the 80 crop trees per acre during the calibration period before any of the large noncrop trees were thinned.

During the calibration period, the average diameter and volume growth were 6.5 percent and 24.1 percent greater, respectively, for the 80 largest trees per acre than the 80 crop trees per acre (table 4) on all treated plots. These differences were much greater on the control plots (24.3 and 64.8 percent, respectively) where fewer of the 80 largest trees per acre were crop trees.

Comparison of Thinning Regimes

The study was designed to produce eight different treatment regimes in which growing stock increased by accumulating basal area at constant rates (regimes 1, 3, 5, and 7), increasing rates (regimes 2 and 4), and decreasing rates (regimes 6 and 8) (see table inside front cover and fig. 6). The actual basal area accumulated matched the theoretical design very closely (fig. 7). At the end of the fifth treatment period, the basal area in treatments 1 and 7 ranged from 70 to 185 square feet per acre. Treatments 2, 4, 6, and 8 followed their proposed patterns of accumulation quite closely. All treatments reduced density well below that of the unthinned control.

Statistical Evaluation of the Treatments

The relation between the treatments and four types of growth—gross basal area growth, gross volume growth, survivor diameter growth, and volume growth percentage—were tested by an analysis of variance (ANOVA) from the original study plan (see footnote 1), shown in table 5. The results are given in table 6 and are discussed below.

All treatments—Over the five treatment periods, the average growing stock, although accumulated differently, was the same for the four constant (1, 3, 5, and 7) and four variable (2, 4, 6, and 8) treatments (102 square feet per acre). The resulting average growth for the five periods also was similar for the constant and variable treatments.

Table 3—Summary of data for all trees crop trees 80 largest and 40 largest trees per acre after calibration thinning in 1963 (age 20) and in 1983 (age 40) with cumulative mortality and cut

Treatment no.	Type	Initial stand (1963) TPA[a]	QMD[b]	BA/AC[c]	VOL/AC[d]	Final stand (1983) TPA	QMD	BA/AC	VOL/AC	Per acre cumulative mort.[e]	cut
		No.	*In*	*Ft²*	*Ft³*	*No.*	*In*	*Ft²*	*Ft³*	– *No.*–	
1	All	353	5.1	49.4	744	52	17.8	89.1	3216	2	300
	Crop[f]	80	5.7	14.4	226	52	17.8	89.1	3216	0	28
	80/acre[g]	80	6.5	18.7	302	52	17.8	89.1	3216	0	98
	40/acre[g]	40	7.0	10.8	117	40	18.5	74.4	2684	0	40
2	All	343	5.2	50.0	729	80	17.1	127.5	4682	3	260
	Crop	80	5.9	15.0	226	75	17.2	121.7	4473	0	5
	80/acre	80	6.6	19.1	297	75	17.3	123.1	4529	0	65
	40/acre	40	7.0	10.6	169	40	18.7	76.0	2819	0	33
3	All	343	5.1	49.0	746	102	15.5	132.9	4908	2	240
	Crop	80	5.8	14.6	225	78	15.9	108.3	4012	0	2
	80/acre	80	6.7	19.4	302	80	16.3	116.5	4313	0	53
	40/acre	40	7.2	11.3	177	40	17.5	67.0	2487	0	25
4	All	333	5.3	50.4	49	138	14.9	168.5	6669	3	192
	Crop	80	5.9	15.3	237	80	15.8	108.7	4101	0	0
	80/acre	80	6.7	19.7	315	80	16.7	121.5	4657	0	35
	40/acre	40	7.1	11.0	180	40	17.6	67.9	2653	0	22
5	All	365	5.0	49.2	720	165	14.0	175.4	6669	10	190
	Crop	80	5.8	14.6	227	78	15.5	102.6	3976	0	2
	80/acre	80	6.4	17.7	285	80	16.2	114.2	4464	0	37
	40/acre	40	6.8	10.1	167	40	17.2	64.8	2576	0	15
6	All	338	5.2	49.9	743	110	15.4	143.0	5204	0	228
	Crop	80	5.8	15.0	233	80	16.0	111.3	4066	0	0
	80/acre	80	6.6	19.2	310	80	16.4	117.5	4307	0	48
	40/acre	40	7.0	10.7	176	40	17.6	67.2	2488	0	22
7	All	328	5.3	50.1	750	223	13.5	221.1	8416	8	97
	Crop	80	6.1	16.1	246	78	14.7	91.8	3528	2	0
	80/acre	80	6.7	19.8	309	80	15.9	110.9	4287	2	17
	40/acre	40	7.2	11.4	180	40	16.7	61.0	2376	0	10
8	All	337	5.2	50.4	768	183	13.7	186.5	6967	8	145
	Crop	80	5.8	14.5	227	80	14.7	94.7	3548	0	22
	80/acre	80	6.8	20.2	330	80	15.9	109.7	4126	0	35
	40/acre	40	7.3	11.6	194	40	16.8	61.9	2334	0	20
Control	All	1727	3.8	138.1	1982	653	9.1	295.1	10869	1073	0
	Crop	80	5.6	13.8	217	77	10.6	47.1	1764	5	0
	80/acre	80	6.9	21.3	365	80	13.8	83.2	2794	0	0
	40/acre	40	7.6	12.5	222	40	15.0	49.2	1958	0	0

[a]Trees per acre.
[b]Quadratic mean diameter.
[c]Basal area per acre.
[d]Volume per acre.
[e]Mortality.
[f]Some crop trees have been replaced with new crop trees so totals may not add.
[g]Trees in the largest 80/acre and 40/acre have been replaced with the next largest tree as trees were cut or died.

Table 4—Growth differences between crop trees and the 80 largest trees per acre during the calibration period

Stand condition	Mean	Standard deviation	Coefficient of variation
Net quadratic mean diameter increment (inches/year):			
Control (n=3)—			
Crop trees	0.37	0.057	15.4
80 largest trees	.46	.078	17.0
Treated (n=24)—			
Crop trees	.62	.038	6.1
80 largest trees	.66	.032	4.8
Net volume increment (cubic feet per acre per year):			
Control (n=3)—			
Crop trees	56.0	4.4	7.9
80 largest trees	92.3	20.3	22.0
Treated (n=24)—			
Crop	87.5	12.9	14.7
80 largest	108.6	11.5	10.6

Fixed treatments—For the four fixed-percentage treatments (1, 3, 5, and 7), the average growth of all four types could be adequately described as linear with growing stock for the five treatment periods. Basal area and volume growth increased, while diameter and volume growth percentage decreased with increasing basal area. Although these trends were linear in the sense that squared and higher terms were not significant in the ANOVA, the underlying relation cannot be expected to be linear because it must pass through the origin and cannot increase indefinitely.

Variable treatments—Treatments 2 and 4, in which basal area increased slowly, together had significantly lower periodic annual increment of volume (343 cubic feet per acre per year) and basal area (8.6 square feet per acre per year) but greater diameter increment (0.49 inches per year) and volume growth percentage (42 percent) than treatments 6 and 8, which accumulated basal area faster (resulting in 410 cubic feet per acre per year, 10.0 square feet per acre per year, 0.41 inches per year, and 40 percent). Comparing the variable-rate treatments 2 versus 4 and 6 versus 8, the treatments maintaining the higher levels of growing stocks (4 and 8) showed greater average volume and basal area increments (although basal area was not significant) but less diameter increment and volume growth percentage. These results are consistent with those in the fixed-percentage treatments.

The periodic annual values for diameter, basal area, and volume growth are given in table 13. Basal area and volume growth percentages also are given.

Table 5—Analysis of variance

Source of variation	Degrees of freedom (5 treatment periods)
Treatments:	
A. Fixed vs. variable percentage treatments	1
B. Among levels of fixed percentage treatments—	
Linear effects	1
Quadratic effects	1
Cubic effects	1
C. Increasing vs. decreasing percentage treatments	1
D. Between levels of increasing percentage treatments	1
E. Between levels of decreasing percentage treatments	1
Error a for testing treatments	16
P periods	4
Treatment X period interactions:	
P X A	4
P X B linear effects	4
P X B quadratic effects	4
P X B cubic effects	4
P X C	4
P X D	4
P X E	4
Error b for testing interactions	64
Total	119

The ANOVA results are the same as those given by Curtis and Marshall (1986) through four treatment periods at Hoskins and agree with results reported for other installations. Basal area and volume increments increase with the level of growing stock and diameter growth decreases. Growth percentages consistently decrease with stocking, thereby indicating that growth per unit of growing stock decreases at greater stocking levels.

Relation of Growth to Growing Stock

To better consider the relation of growth to growing stock, data for plots from all treatments and the controls were used, which give a wider range in growing stock than in the ANOVA. A nonlinear regression model given and discussed by Curtis and Marshall (1986) of the form,

$$Y = e^{a}X^{b}e^{cX} ,$$

was used to describe the relation of growth to growing stock for each period. The model was fit in the form,

$$\ln Y = a + b \ln X + cX ,$$

Table 6—Analysis of variance results for periodic annual gross volume and basal area growth, and survivor quadratic mean diameter periodic annual increment and volume growth percentage

	P-values[a] and mean square errors			
	Volume		Basal	
Source of variation	PAI	Growth percent	area PAI	Diameter PAI
A. Fixed vs. variable	0.882	0.332	0.619	0.755
B. Fixed (linear)	.000**	.000**	.000**	.000**
B. Fixed (quadratic)	.158	.901	.168	.081
B. Fixed (cubic)	.412	.421	.557	.999
C. Increasing vs. decreasing	.000**	.004**	.000**	.000**
D. Between increasing	.000**	.003**	.023*	.000**
E. Between decreasing	.000**	.003**	.133	.001**
Error a mean square	1085.017	0.674	0.904	0.0034
P periods	.000**	.000**	.000**	.000**
P X A	.799	.790	.273	.191
P X B (linear)	.000**	.127	.000**	.000**
P X B (quadratic)	.283	.214	.001**	.016*
P X B (cubic)	.482	.271	.773	.799
P X C	.007**	.046*	.000**	.000**
P X D	.460	.977	.053	.000**
P X E	.003**	.024	.002**	.026*
Error b mean square	487.040	0.281	0.072	0.0003

[a] P is the probability of a larger F, given that the null hypothesis of no difference among means is true. Significance levels— *: 0.01 p 0.05; and **: p 0.01.

where Y is the measure of growth, X is the measure of growing stock, and ln is the natural logarithm. Period mean values of growing stock are used to represent the average stocking that produced the observed periodic annual increment. This facilitated comparisons of growth periods of different lengths. The regression equations for growth and different measures of growing stock were plotted from the treatment means by period.

Basal area increment—Regressions were fit for gross basal area growth (dG) by using basal area per acre (G) and relative density (RD) as measures of growing stock of the form,

$$\ln dG = a + b \ln G + cG \text{ , and}$$

$$\ln dG = a + b \ln RD + cRD \text{ .}$$

The measure of relative density used is that of Curtis (1982). The results are graphed for basal area and relative density in figure 8 (a and b, respectively). In both cases, basal area increment seems to reach a maximum at densities between the thinned plots and the controls.

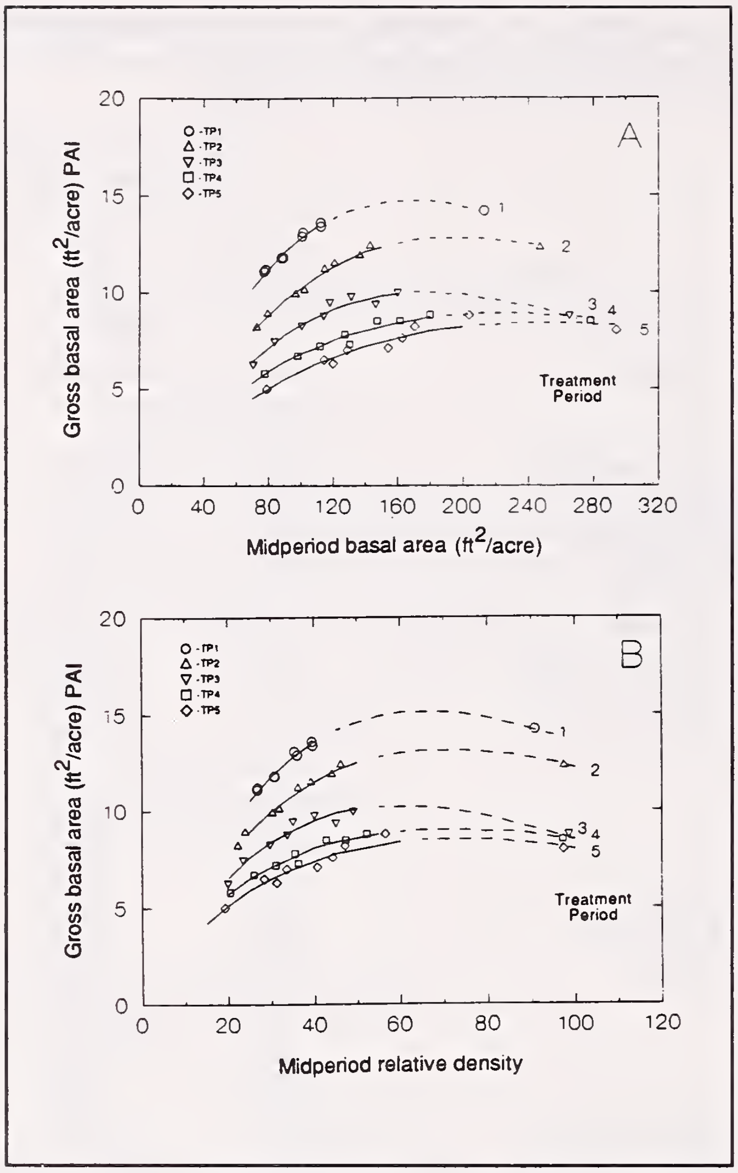

Figure 8—Relation of periodic annual gross basal area increment to mean period basal area growing stock (a) and relative density (b) by treatment period for all plots. Solid lines represent the range of the thinned plot values; dashed lines extend to the upper margin of the control plot values. R^2 and RMSE are for the transformed variable ln(dG).

Volume increment—Regressions of the same form as above were used to express gross volume increment (dV) as functions of basal area per acre (G), volume per acre (V) and relative density (RD):

$$\ln dV = a + b \ln G + cG ,$$

$$\ln dV = a + b \ln V + cV , \text{ and}$$

$$\ln dV = a + b \ln RD + cRD .$$

These curves are presented in figure 9 (a, b, and c, respectively). These trends are similar to those for basal area but are steeper relative to the level of growing stock; they generally do not show a peak within the range of stocking, although some flatten out in the upper range of the controls in the latter periods. One exception is treatment period 3. Scatter plots of basal area and volume growth over midperiod growing stock show decreased gross growth for the control plots 10 and 22 during this period. Although the reason for this is not known, height measurements and the resulting short period are suspect.

Diameter increment—Using basal area (G) and relative density (RD) as measures of growing stock, regressions of the form,

$$dD = a + bG + c\,G^2 , \text{ and}$$

$$\ln dD = a + bRD ,$$

were fit for periodic diameter growth of the surviving trees (dD). A relative density squared term was not significant in any period. The results for G and RD are shown in figure 10 (a and b, respectively) and show a steep decrease in growth with increasing growing stock.

Net growth—The above analysis and ANOVA were done by using gross basal area, volume growth, and survivor diameter growth because these should represent the biological potential of a site for growth. To date there has been little mortality in any of the treated plots. Net growth therefore will be almost identical to gross basal area, volume growth, and survivor diameter growth and will produce essentially the same results through the range of the treated plots. There has been, however, considerable mortality in the control plots, which has caused the net basal area and volume growth to be less than the gross growth. The net growth on the controls also has been less than that of the lighter thinning treatments thereby resulting in a peak in net growth/growing stock between the lightest thinning treatments and the control. The slopes of the net diameter-increment curves still decrease sharply for the treatments but flatten out in the high densities of the control plots (fig. 11).

Twenty-Year Stand Development

The standard LOGS summary tables given in previous LOGS installation reports are given in appendix 1 (tables 8-16). Stand development tables are presented for each treatment in English and metric units in appendix 2 (tables 17-25).

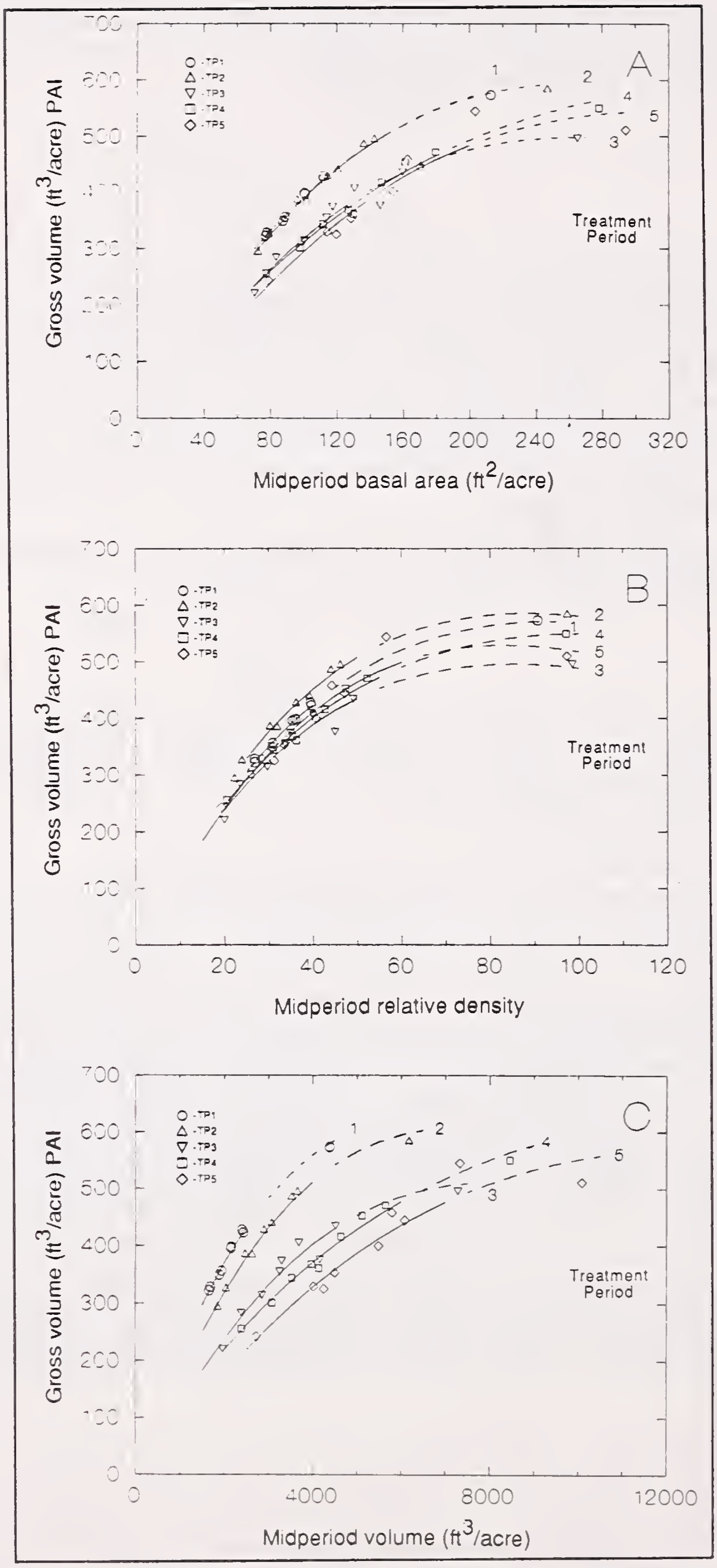

Figure 9—Relation of periodic annual volume increment to mean period basal area growing stock (a), volume growing stock (b) and relative density (c) by treatment period for all plots. Solid lines represent the range of the thinned plot values; dashed lines extend to the upper margin of the control plot values. R^2 and RMSE are for the transformed variable ln(dV).

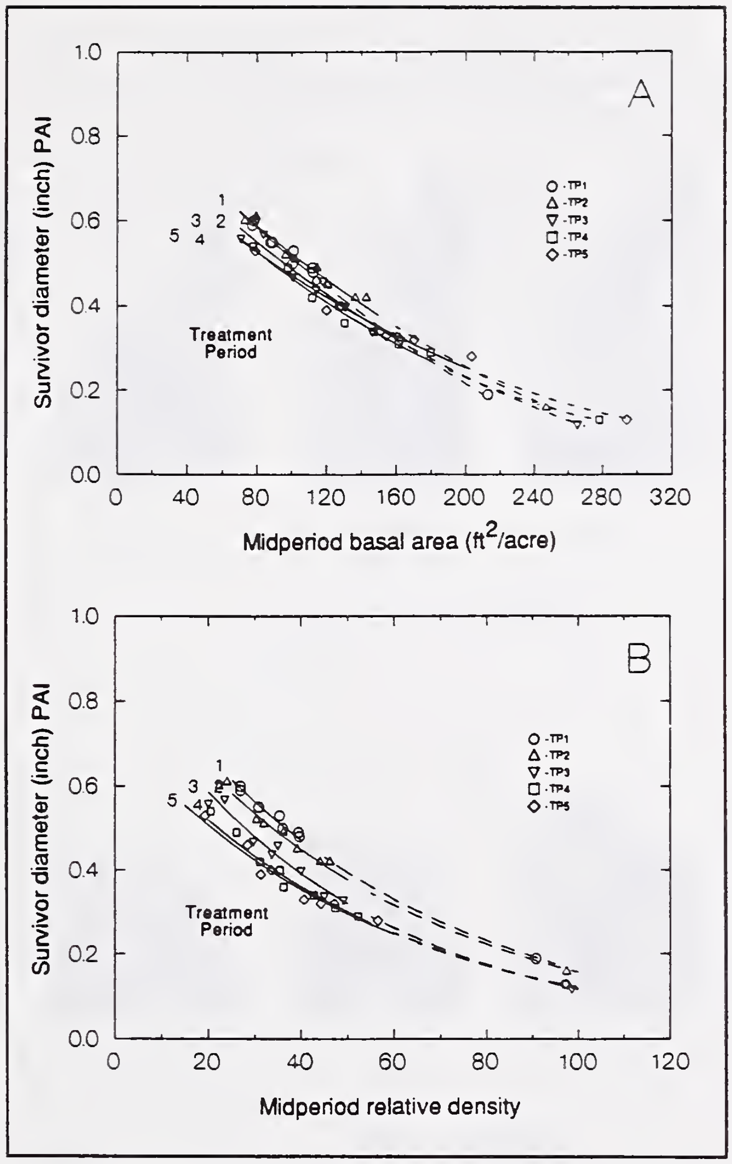

Figure 10—Relation of periodic annual survivor quadratic mean diameter increment to mean period basal area growing stock (a) and relative density (b) by treatment period for all plots. Solid lines represent the range of the thinned plot values; dashed lines extend to the upper margin of the control plot values. R^2 and RMSE are for dD in (a) and for the transformed variable ln(dD) in (b).

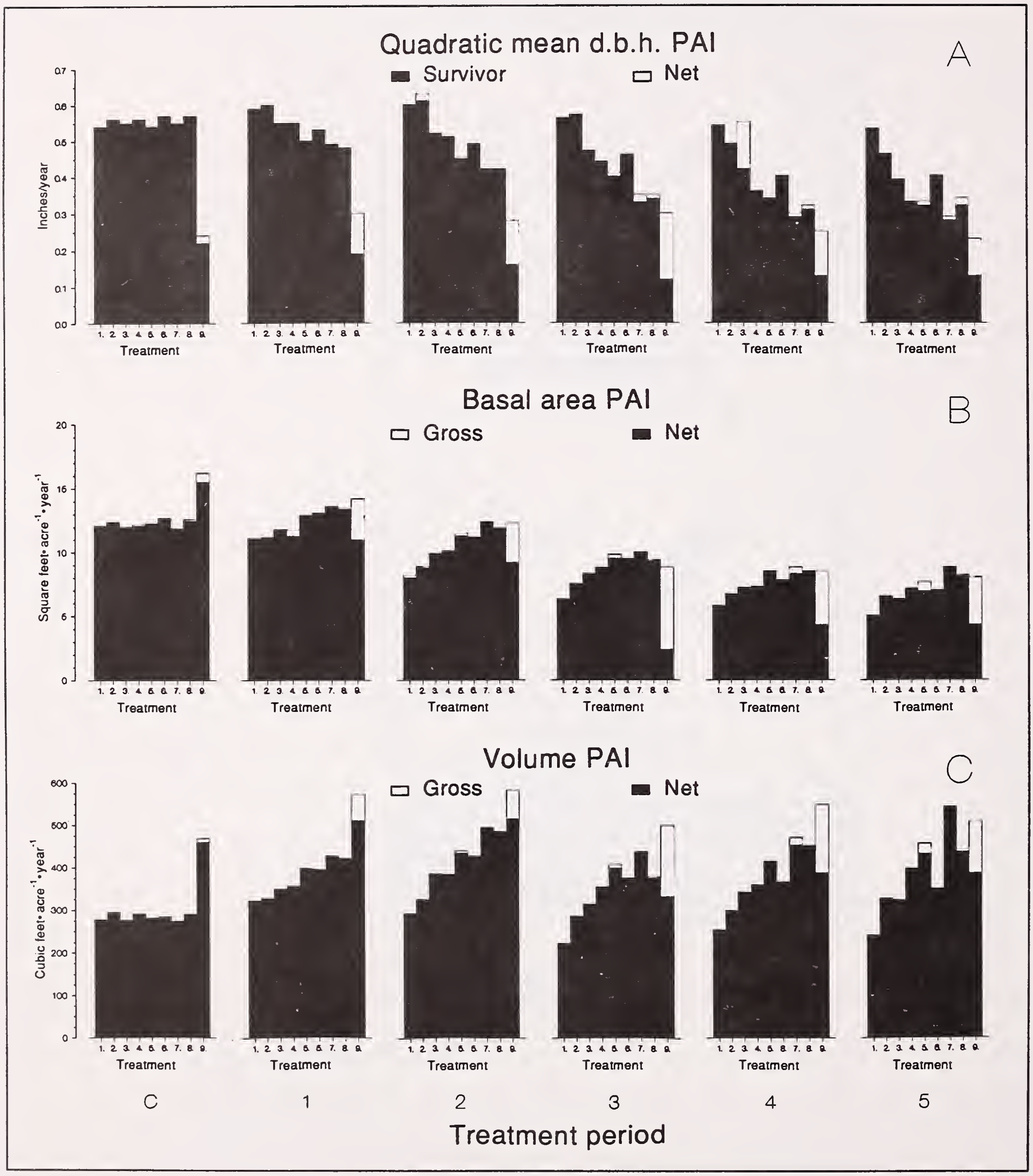

Figure 11—Net and survivor periodic annual quadratic mean diameter increment (a) and net and gross periodic annual basal area (b) and volume (c) increments by treatment and period.

Stand height, site index, and height growth—The height of the 40 largest d.b.h. trees per acre is given in table 12 by treatment. The average height for the 40 largest d.b.h. trees on all plots is shown in figure 12 along with site index (King 1966). Although not the method of site tree selection given by King (1966), the site estimates using the 40 largest d.b.h. trees seem reasonable and stable at around 135 feet on the control plots. The average height of the control plots was 3.1 feet greater than the thinned plots after the calibration thinning, 43.0 and 39.5 feet, respectively (significant at $p < 0.01$). This further suggests that some of the larger trees may have been removed during the calibration thinning, which would give invalid estimates on the treated plots. This difference is, however, no longer significant in 1983 with the unthinned control plots averaging 101.0 feet and the treated plots averaging 100.9 feet.

Number of trees and basal area—Initial number of trees per acre differed among treatments. After the calibration, the trees per acre ranged from 300 to 390 at stand age 20. By age 40, treatment 1 (the heaviest thinning,) had been reduced to 50 and 55 trees per acre and, treatment 7 (the lightest thinning,) had between 210 and 240 trees per acre. During this 20 years, the control plot decreased from 1,885 to 1,610 trees per acre to a current 885 to 695 trees per acre because of mortality (tables 8 and 12, fig. 13). Basal area, which was controlled to establish different levels of growing stock, increased from about 50 square feet per acre on all plots after calibration to only 69 square feet per acre in treatment 1 and 186 square feet per acre in treatment 7. The unthinned control plots increased from an average of 138 to 295 square feet per acre (tables 10 and 13, fig. 13).

On the control plots, 93 percent of the trees initially were less than 6 inches d.b.h. As of the 1983 remeasurement, 67 percent had died and 26.1 percent had grown to 6 inches or greater. After the calibration thinning, 80 percent of trees on the treated plots were less than 6 inches d.b.h. In the subsequent thinnings on the heaviest and lightest treatments (1 and 7, respectively), 15 and 6 percent, respectively, of those trees initially less than 6 inches d.b.h. were cut or died, though mortality was minor and primarily limited to the lighter treatments. All remaining trees have been harvested or survive as merchantable trees of 6 inches d.b.h. or greater.

The d/D ratio over all five treatment thinnings averaged 0.94. The extreme values were 0.67 and 1.18; both occurred in the fifth treatment period when there were fewer noncrop trees available,which made the d/D requirements more difficult to obtain. There did not seem to be any relation between d/D with treatment or treatment periods, although the ratio became more variable in latter periods as a result of less choices of noncrop trees to cut.

Crown ratios—Crowns were measured only at the end of the fifth treatment period (age 40). The initial stand (age 20) was uniform with height-to-live-crown of only 7 to 9 feet. The effects of the treatments on the crowns are quite evident after the five treatment periods. For the 40 trees with the largest d.b.h., the perecentage of live crown ratio (and height-to-live-crown in feet) averaged 59 percent (40 feet), 54 percent (46 feet), 46 percent (57 feet), and 41 percent (60 feet) for the increasing treatments (1, 3, 5, and 7, respectively);) 54 percent (47 feet) and 44 percent (58 feet) for the increasing treatments (2 and 4); and 54 percent (46 feet) and 45 percent (54 feet) for the decreasing treatments (6 and 8). The controls averaged 29 percent live crown ratio and 72 feet to live crown. This demonstrates the longer crowns maintained by the lower levels of growing stock.

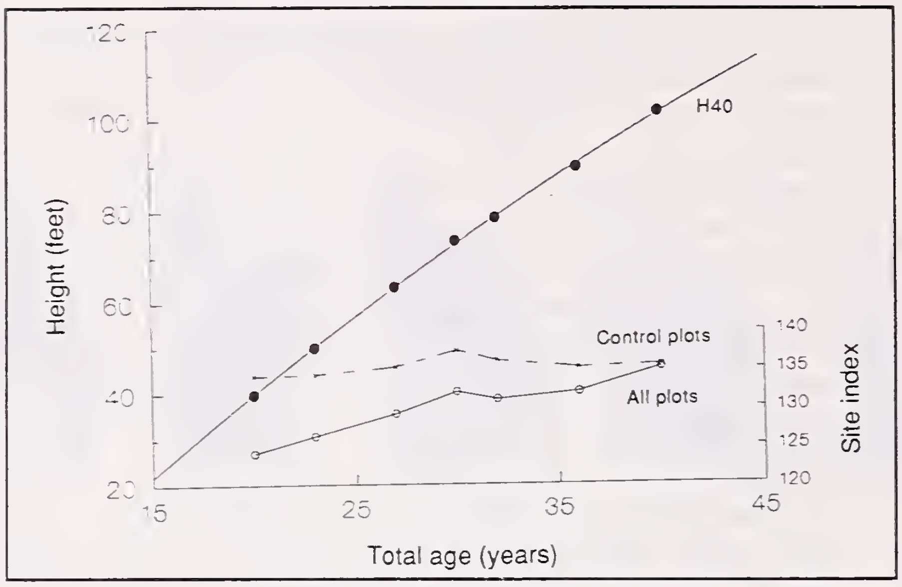

Figure 12—Height of the 40 largest trees per acre and site index estimates (King 1966).

Basal area and volume growth—The previous discussion on the relation of growth to level of growing stock showed that gross basal area and volume increment are both highly related to growing stock, volume more than basal area (table 13). Both increments increased with greater stocking. Net stand growth also showed decreases in the heavy thinnings and increased with greater stocking. In contrast, net growth is reduced at the high stocking levels of the controls due to mortality; and maximum growth occurred in the lightest thinning treatments (fig. 11, b and c).

Diameter and diameter growth—Average stand diameter growth responded well and quickly to a late thinning in this 20-year-old, high-density stand. Treated plots grew 2.3 times more in net diameter growth than the controls did during the calibration period. The attained quadratic mean diameter, after thinnings, is shown in figure 14 by treatment (tables 9 and 12). At the time of the 1983 remeasurement (age 40), diameters were almost twice as large on the heaviest thinning as on the control (17.8 to 9.1 inches), and the lightest thinning (13.7 inches) was 1.5 times the control. The use of net diameter growth alone can be a misleading measure of thinning response because of the effects of mortality (Curtis and Marshall 1986) as shown in figure 11a. The diameter growth on the surviving trees is similar to the net growth for the treated plots, which have experienced little or no mortality. In the control plots, the survivor diameter growth is much lower because of the mortality of smaller understory trees increasing the stand net diameter growth. The increase in diameter due to thinning (and very minor mortality) for treatments 1, 3, 5, and 7 accounts for 12.2, 8.1, 6.5, and 4.8 percent, respectively, of the net growth. On the controls, the increase due to mortality was 39.1 percent of the net growth.

The cumulative growth on the surviving trees (not including increases in quadratic mean d.b.h. due to thinnings or mortality) is greatest for the the heaviest thinnings and decreases with greater levels of growing stock. Competition at all levels has reduced growth of the crop trees and the 40 largest diameter trees per acre over that of the heaviest thinning (fig. 15). Response has continued to be strong with the largest increases coming from the heaviest thinnings, as expected from the ANOVA results (fig. 16).

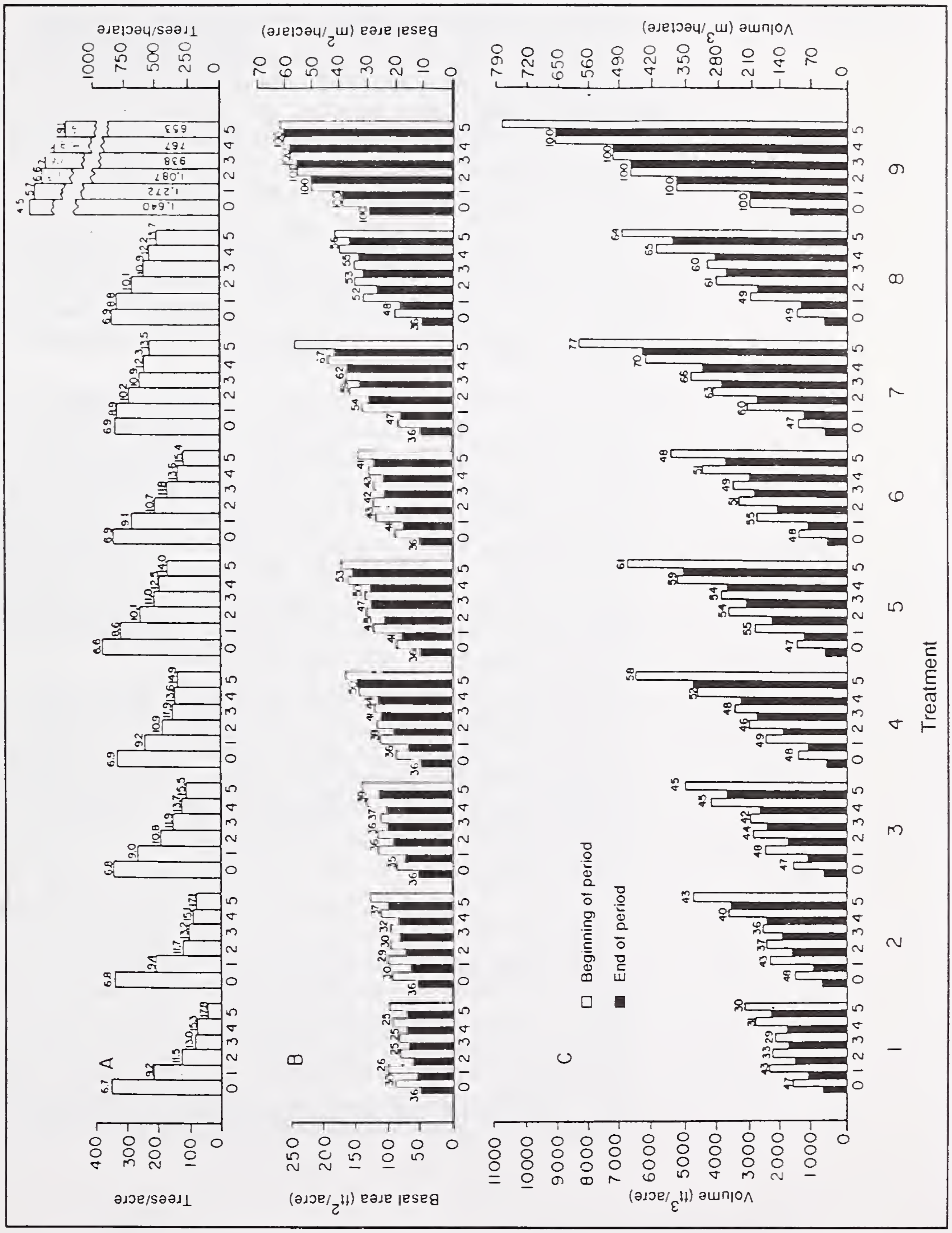

Figure 13—Changes in (a) trees/acre, (b) basal area, and (c) volume for all thinning treatments. Zero is the calibration period and 1-5 are the treatment periods 1 through 5. Number above bar is (a) quadratic mean diameter; (b) basal area after treatment divided by basal area of control × 100; and (c) volume in live trees at the end of a treatment period divided by the volume of the control × 100.

Volume yield and production—The calibration thinning removed an estimated 1,238 cubic feet per acre on the treated plots of an average diameter of 3.4 inches. All treatments had less than 200 board feet per acre removed in merchantable trees 7.6 inches d.b.h. and larger (fig. 17). As of the 1983 remeasurement (40 years), the control contained more cubic-foot volume per acre (10,869 ft^3/acre) than the lightest thinning treatment (treatment 7,8,416), and over three times that of the heaviest thinning treatment (treatment 13,216) (tables 11 and 12, fig. 13). Thinnings have removed from 12 to 48 percent of the gross-cubic-foot yield on the treated plots. In board feet per acre, treatment 7 contained 38,574 board feet for trees 7.6 inches d.b.h. and greater, 4,530 board feet more than the control and 22,309 board feet more than treatment 1. Most of the merchantable board-foot volume in the thinned plots is in trees 13.6 inches and greater (73 to 100 percent) compared to only 27 percent in the control (fig. 18, table 26).

The cumulative net yield includes the standing volume plus the volume removed in thinnings; the gross cumulative yield also includes volume lost through mortality. The control has continued to outproduce all treatments in total gross and net cubic-foot yield (omitting volume removed during the calibration thinning), although the production on the lightest thinning treatments (which include negligible mortality) is catching up to the net volume yield of the control for trees 1.6 inches and larger (fig. 19, table 13). For trees 7.6 inches and greater, treatment 7 has produced more cubic-foot volume than the controls and treatment 8 nearly equaled the control. In board feet, though, only treatments 1, 2, and 3 have produced less volume than the control for trees 7.6 inches and larger (fig. 20, table 26).

Periodic and mean annual increments—Periodic annual increment (PAI) and mean annual increment (MAI) in net volume for trees 1.6 inches d.b.h. and larger are shown in figure 21 and tables 27 and 28. Although the trends are quite variable, PAI seems to be leveling off or beginning to fall in the controls; MAI continues to increase with the differences between treatments becoming greater. Even with a downward PAI trend, all treatments still are far from culmination of MAI because PAI is nearly twice MAI in most treatments.

Mortality—Mortality occurred in all thinned treatments except treatment 6 (tables 7 and 14). In all cases, the volume lost was less than 1 percent of the gross volume yield through age 40, except for treatment 5 where it was 1.5 percent. The control plots had considerable mortality; they lost an average of 1,073 trees in 20 years (53.7 trees per year) or about 62 percent of the trees present at age 20. This was about 14 percent of the total gross volume yield on the controls. The trees that died were all less than the quadratic mean treatment d.b.h. and in the controls averaged about half the quadratic mean d.b.h. Apparently all mortality is due to natural self-thinning or crowding, and none caused by animals or root rot has been identified.

Table 7—Total number of trees, basal area, and volume per acre in mortality by treatment, 1963-83

Treatment	Number of trees	Basal area	Volume
	Per/acre	*Ft²/acre*	*Ft³/acre*
1, fixed 10	1.7	0.10	1.7
3, fixed 30	1.7	.17	2.7
5, fixed 50	10.0	4.07	129.0
7, fixed 70	8.3	2.60	83.7
2, variable 10-50	3.3	.33	5.3
4, variable 30-70	3.3	.30	4.9
6, variable 50-10	0	0	0
8, variable 70-30	8.3	1.30	38.9
9, control	1073.3	68.97	1787.2

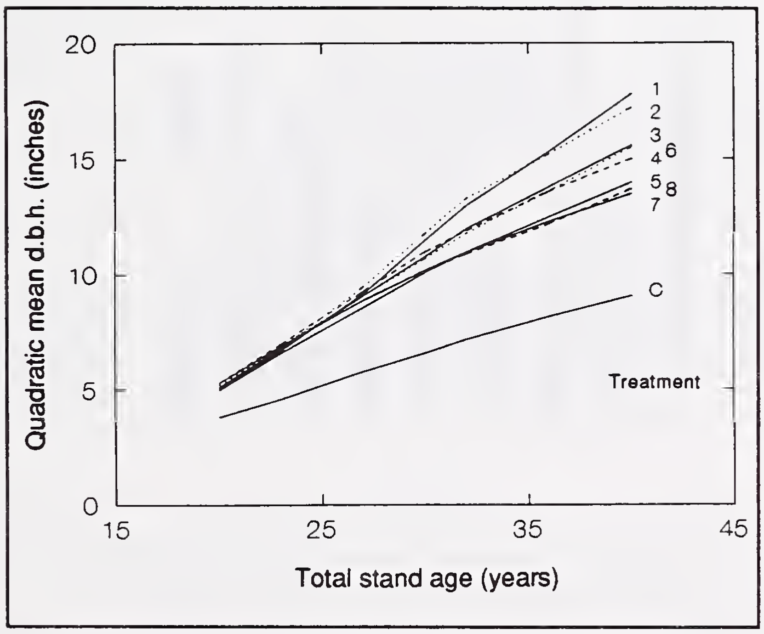

Figure 14—Attained quadratic mean diameter (all trees) by stand age for treatments and control.

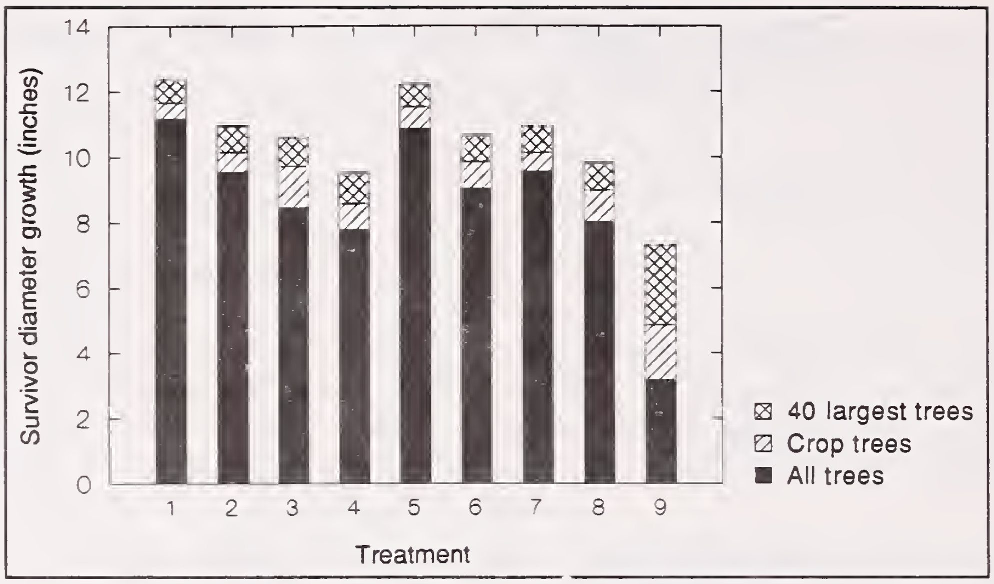

Figure 15—Cumulative diameter increment, from study establishment to the end of the fifth treatment period, of 40 largest trees per acre, crop trees, and all trees by treatment.

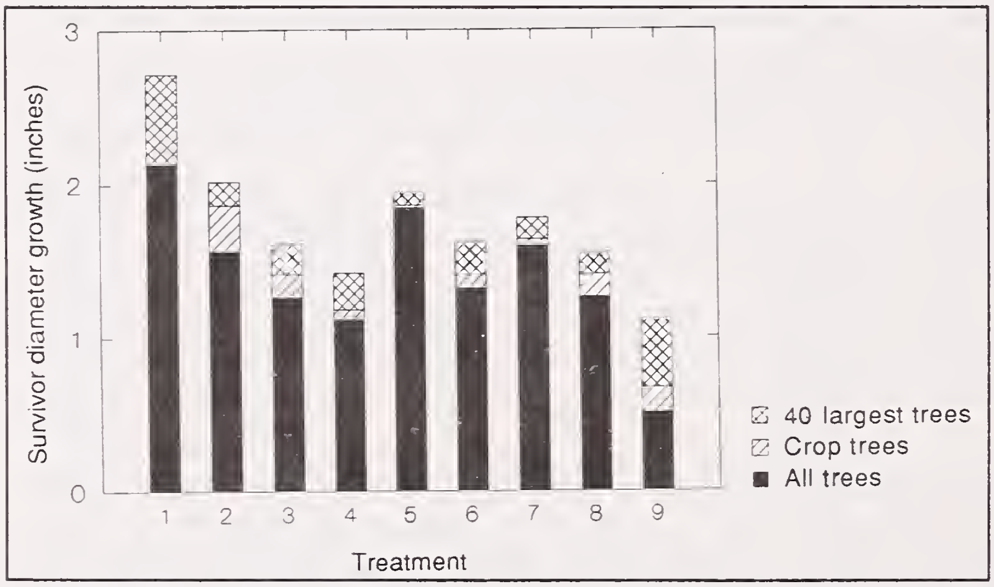

Figure 16—Periodic diameter increment of the 40 largest trees per acre, crop trees, and all surviving trees, for the fifth treatment period.

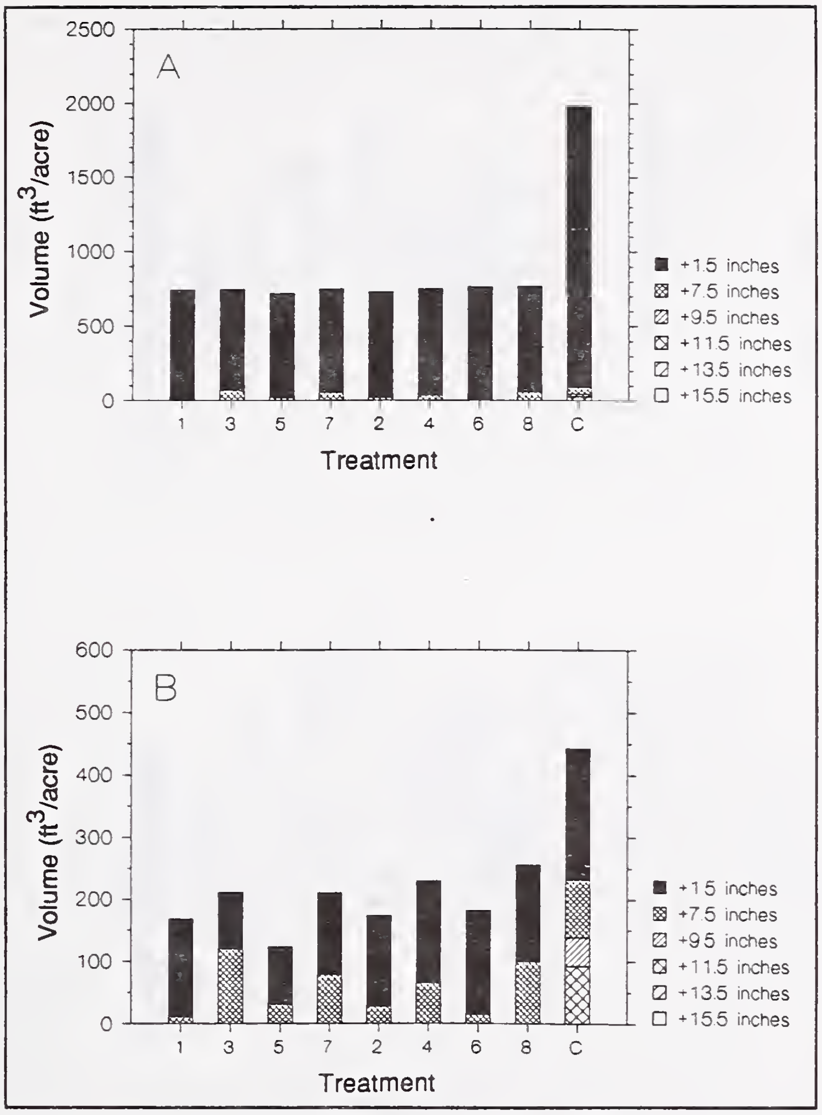

Figure 17—Initial volume after the calibration thinning (age 20), by tree size classes for (a) cubic feet per acre and (b) board feet per acre.

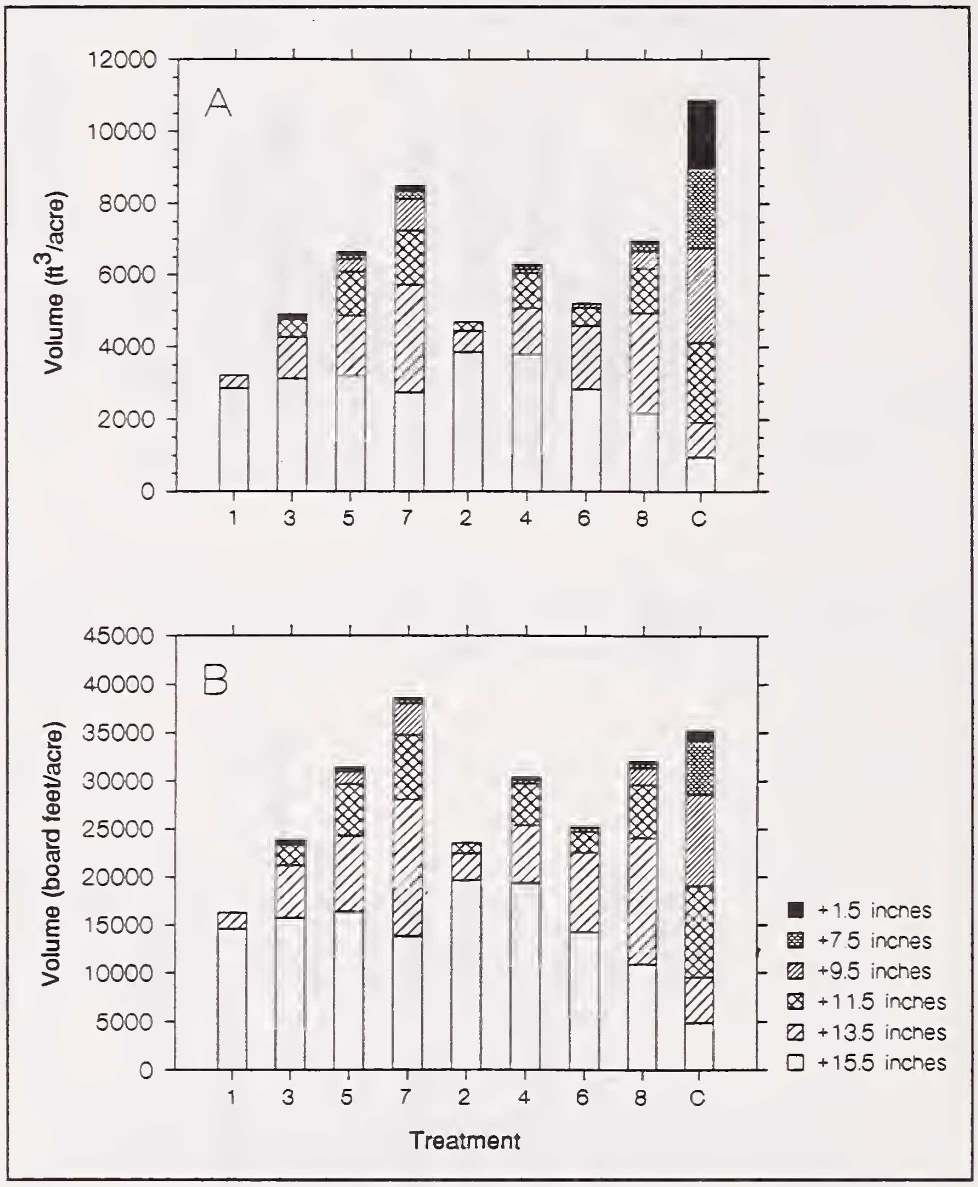

Figure 18—Standing volume at the end of the fifth treatment period (age 40), by tree size classes for (a) cubic feet per acre and (b) board feet per acre.

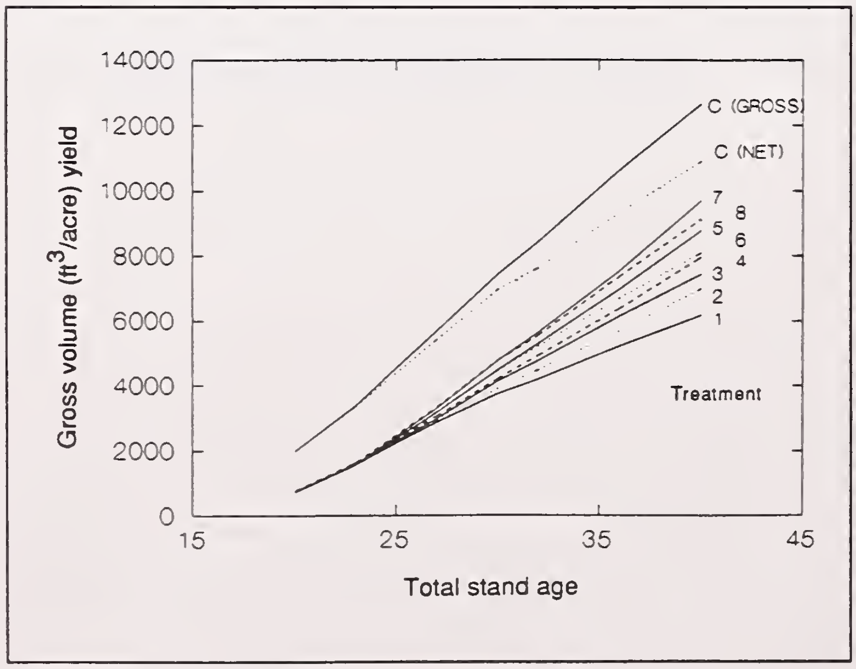

Figure 19—Cumulative gross cubic volume yield in trees 1.6 inches d.b.h. and larger (material removed in the calibration cut excluded) by stand age, through the end of the fifth treatment period by treatment.

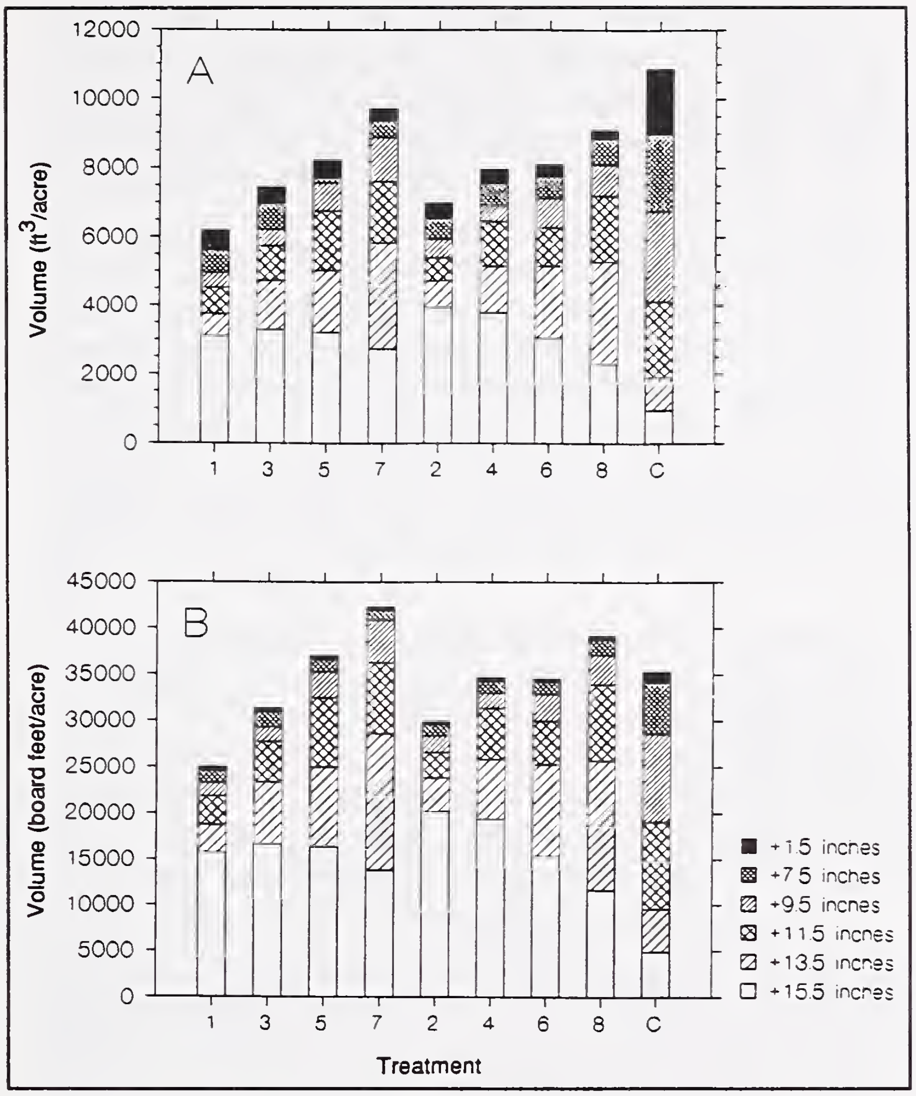

Figure 20—Volume production at the end of the fifth treatment period (age 40), by tree size classes. Values are sums of live stand at end of fifth treatment period plus previous thinnings (calibration cut excluded) for (a) cubic feet per acre and (b) board feet per acre.

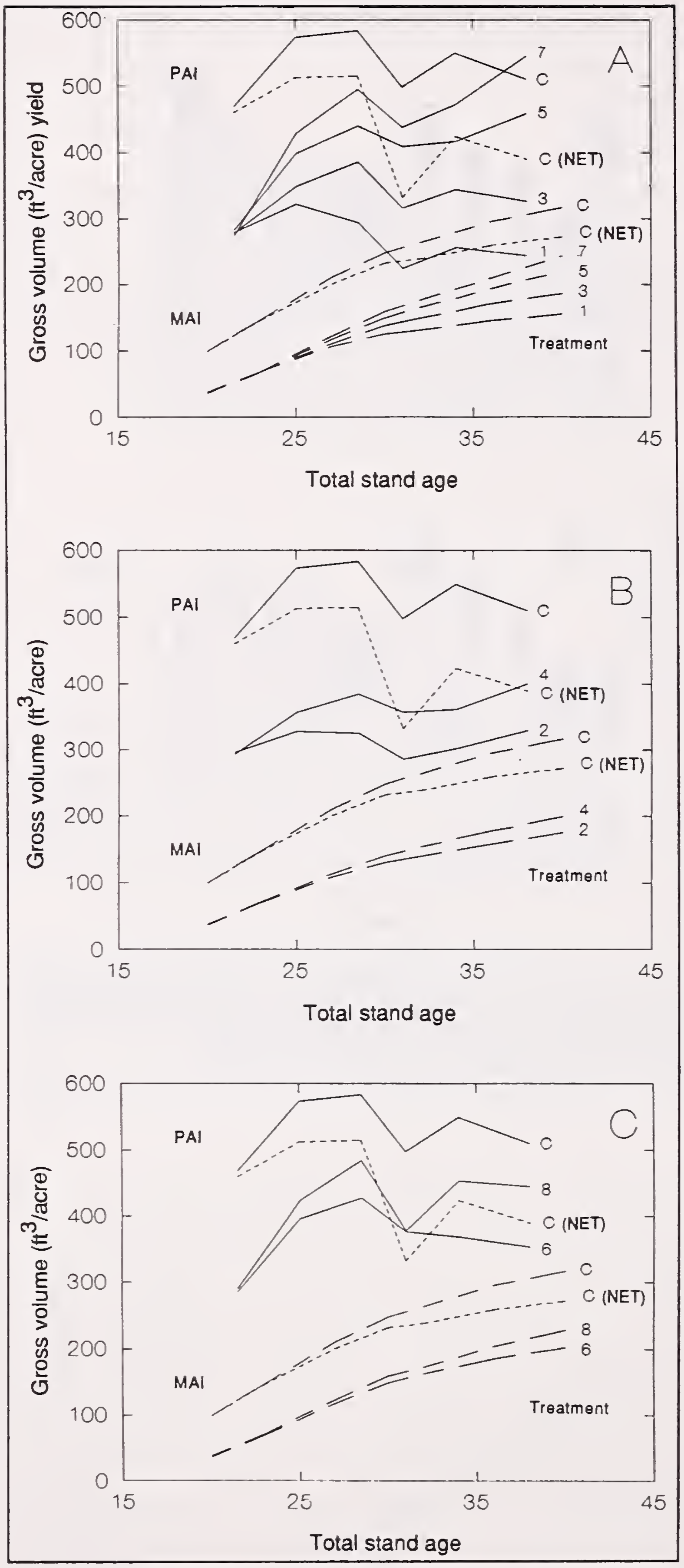

Figure 21—Comparisons of trends of mean annual gross increment (MAI) in volume and of periodic annual gross increment (PAI) in volume, by stand age: (a) fixed treatments (1, 3, 5, and 7); (b) increasing treatments (2 and 4); and (c) decreasing treatments (6 and 8).

Discussion

The results of this study indicated that precommercial thinning of dense, 20-year-old stands will give good results. The calibration thinning represented a late precommercial thinning (Reukema 1975). Even with the initial high stockings and lateness of the treatment, the trees responded immediately to release with a 131.25 percent increase in net diameter growth over the controls.

Changes in tree vigor and crown position over time often make initial choices of crop trees inappropriate. Strict spacing requirements add to the difficulties of crop tree selection; this study suggests that spacing guidelines caused some less-than-suitable crop trees to be chosen. The result of this type of selection is not known, but some reduction in stand growth could occur from removal of the better growing trees. When precommercial thinning is done in older, dense stands, where tree quality is probably a better criteria for crop tree selection than spacing, the spacing guidelines could be relaxed. Markers and cutters should be given the flexibility to work with the existing stand structure and release the better trees. A future study might consider what kind of tree should be selected.

Basal area and volume growth increased with growing stock, and diameter growth decreased. The curve for gross basal area growth flattened out at higher densities, although the curve for volume did not. There may be a trend towards a flatter volume growth curve in the later periods as the lighter treatments add growing stock. This demonstrates the inherent differences in the relation of basal area growth to growing stock and of volume growth (of which height growth is a component) to growing stock. Because of this difference, basal area growth should not be used as the criteria for judging volume growth or potential volume growth.

Individual periodic gross volume growth curves do not show the clear plateau hypothesized in Langsaeter's (1941) (as presented by Braathe 1957) zone III (fig. 22). During the early periods, the treated plots seemed to be in zone I, where growth is directly proportional to growing stock, and zone II, where growth decreases with increases in growing stock. In the last treatment period, the lightest thinning (treatment 7) had volume growth similar to the controls with 27.3 percent less growing stock; this may indicate the beginning of a plateau. In any case, the tradeoffs between stand volume production and tree sizes are large. The control has yielded more cubic-foot volume, but the lightest thinnings have produced similar total volumes, and all but the heaviest thinnings have greater merchantable cubic-foot and board-foot volumes than the control. In both cases, most of the volume for the thinned stands is in larger trees and net growth is greatly decreased at the high densities of the controls owning to mortality. These results are consistent with the other LOGS installations reported by Curtis and Marshall (1986).

Periodic annual increment for the control probably has culminated, although the curves for the treated stands are fairly flat. The mean annual increment for all treatments and the control continues to increase. This suggests the possibility of longer biological rotations resulting from the treatments.

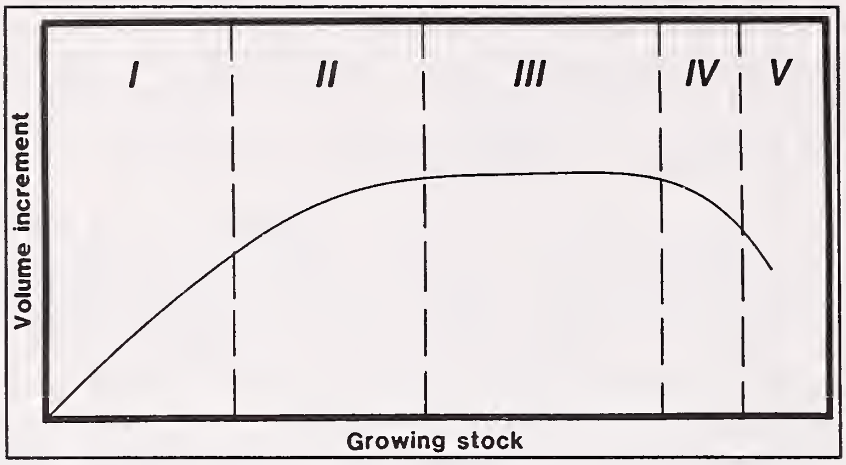

Figure 22—Relation between volume increment and growing stock, as hypothesized by Langsaeter (adapted from Braathe 1957). Roman numerals denote Langsaeter's "density types."

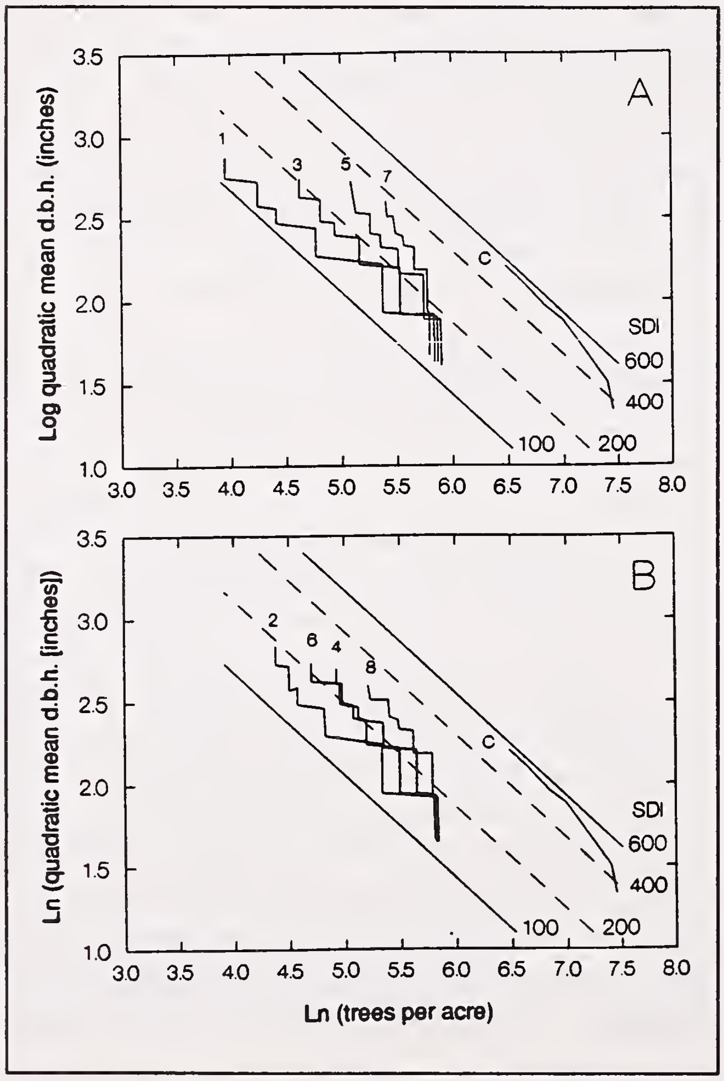

Figure 23—Stand density management diagram (after Long and others 1988) for (a) control and fixed treatments and (b) variable treatments.

The development of the Hoskins plots is shown in figure 23 on a Reineke type-stand-density-management diagram proposed by Long and others (1988). Long (1985) suggests that the lower limit of self-thinning occurs at about 60 percent of maximum stand density index (SDI) and that the lower limit of "full site occupancy" is at about 35 percent. The maximum SDI for coastal Douglas-fir is near 600 (Reineke 1933) (RD = 100) and is similar to estimates given by Drew and Flewelling (1979).[3] The control had an initial SDI of 367 (61 percent of maximum) with little apparent past mortality. During the next period, 87 trees per acre died, which suggests the stand was near the point of self-thinning. In the later periods, the control approaches and tracks just below a maximum SDI line of 600. The calibration thinning reduced the treated plots to an SDI of near 120 (20 percent of maximum). Mortality has been negligible through the fifth treatment period with the lightest thinning, treatment 7, reaching an SDI of 357 (60 percent of maximum) at the last remeasurement. Mortality would be expected to begin in this treatment during the next period. It appears that Long's (1985) lower limit of full site occupancy and maximum stand growth (35 percent) may be low. Management in the range of 40 to 60 percent of maximum SDI (RD40 to RD60) should achieve near-maximum stand volume growth; diameter growth will be highest below these levels.

Financial analysis of the Hoskins study was performed after the fourth treatment period by Tappeiner and others (1982). They found that even though the treatments may not represent operational regimes (short thinning cycles and removal of some of the larger trees) and the thinnings provided low returns, the resulting increase in diameters gave substantially greater future returns. The large increases in diameter in the heaviest thinnings did not offset the resulting decrease in volume growth because of depleted growing stock levels; returns were lower than the lighter treatments that maintained high levels of growing stock but still resulted in increases in diameter.

The management implications of this study stress the importance of early stocking control and the tradeoffs between a level of growing stock that maintains high stand volume growth and individual tree diameter growth. Early thinnings allow small trees to grow into merchantable classes quickly and lessen losses from mortality. Heavy early thinning will give high individual tree growth rates but will decrease stand growth and the options for future management. Lighter thinnings have less returns initially from the harvest of small trees, but maintain stand growth and still significantly reduce mortality losses. Thinning stands below RD60 (or 60 percent of maximum SDI) seems to greatly reduce losses to mortality. Curtis and Marshall (1986) suggest that one possible management strategy would be to encourage diameter growth in the early stages of stand growth when volume growth is on unmerchantable stems by maintaining light stockings (relative densities of 20 to 40). As stands develop and trees become merchantable, densities would be allowed to increase up to a maximum, near relative density 60, for high stand volume growth. On good sites, however, management of Douglas-fir can apparently be quite flexible in frequency, intensity, and type of thinnings and still maintain high diameter and stand volume growths.

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[3] In terms of relative density (RD) used earlier, the maximum value for Douglas-fir is around 100 and corresponds very closely to the maximum SDI of 600. For the seven measurements on all plots, the r^2 = 99.5 percent between RD and SDI, thereby indicating the virtual equivalence of percentage of maximum SDI and RD.

Several important questions still remain. The thinnings applied have decreased the rings per inch (at or below six for the heaviest thinning treatments) and have maintained low crowns and probably larger branches particularly in the heaviest thinnings. All these factors in addition to the percentages of juvenile wood produced may be important in influencing wood quality and value but have not yet been addressed. Through continued remeasurement of these plots, there may be opportunities to answer questions about the effect of thinning on tree quality as well as the effect of thinning on culmination of MAI, economic rotations, and self-thinning mortality trajectories in thinned and unthinned stands.

Metric Equivalents

1 inch = 2.54 centimeters

1 foot = 0.3048 meter

1 square foot = 0.09290 square meter

1 acre = 0.4047 hectare

1 square foot per acre = 0.2296 square meter per hectare

1 cubic foot per acre = 0.06997 cubic meter per hectare

1 mile = 1.609 kilometers.

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Appendix 1

LOGS Summary Tables

Table 8—Number of live trees per acre, by treatment, plot, treatment period, year, and stand age (years)

		Calibration		1st period		2d period		3d period		4th period		5th period	
Treatment	Plot no.	Start (1963, 20)	End (1966, 23)	Start (1966, 23)	End (1970, 27)	Start (1970, 27)	End (1973, 30)	Start (1973, 30)	End (1975, 32)	Start (1975, 32)	End (1979, 36)	Start (1979, 36)	End (1983, 40)
1	3	345	345	210	210	115	115	85	85	70	70	50	50
	8	380	375	225	225	120	120	80	80	70	70	50	50
	20	335	335	210	210	120	120	85	85	70	70	55	55
2	4	360	360	220	220	135	135	105	105	95	95	85	85
	15	325	325	185	185	100	100	75	75	70	70	65	65
	17	345	340	215	215	40	135	110	110	105	105	90	90
3	7	390	390	295	295	200	200	160	160	145	145	115	115
	11	340	340	240	240	160	160	125	125	105	105	85	85
	21	300	295	220	220	165	165	135	135	120	120	105	105
4	5	390	390	285	285	205	205	180	180	160	160	155	155
	18	320	320	245	245	185	185	165	165	150	150	145	145
	23	290	280	200	200	150	150	135	135	125	125	115	115
5	9	355	355	315	315	250	250	215	215	195	195	175	170
	24	345	345	280	280	230	230	200	200	180	180	165	160
	27	395	390	340	340	270	265	225	220	205	205	170	165
6	1	325	325	275	275	210	210	170	170	145	145	115	115
	2	360	360	300	300	225	225	180	180	150	150	115	115
	25	330	330	275	275	195	195	155	155	130	130	100	100
7	12	330	330	330	330	300	300	275	275	260	255	240	235
	14	325	325	310	310	270	270	245	245	230	230	210	210
	19	330	330	330	330	290	290	265	260	240	230	225	225
8	6	375	370	360	360	300	300	260	260	240	240	200	195
	13	330	330	320	320	270	270	240	235	220	215	190	185
	16	305	305	300	300	255	255	225	225	205	205	170	170
Control	10	1885	1830	1830	1425	1425	1205	1205	1100	1100	885	885	735
	22	1610	1430	1430	1110	1110	965	965	800	800	695	695	600
	26	1685	1660	1660	1280	1280	1090	1090	915	915	720	720	625

Table 9—Quadratic mean d.b.h. (inches) of all live trees, by treatment, plot, treatment period, year, and stand age (years)

		Calibration		1st period		2d period		3d period		4th period		5th period	
Treatment	Plot no.	Start (1963, 20)	End (1966, 23)	Start (1966, 23)	End (1970, 27)	Start (1970, 27)	End (1973, 30)	Start (1973, 30)	End (1975, 32)	Start (1975 32)	End (1979, 36)	Start (1979, 36)	End (1983, 40)
1	3	5.1	6.9	7.0	9.4	9.8	11.7	11.8	12.9	13.1	15.3	15.9	18.0
	8	4.9	6.4	6.7	8.9	9.6	11.3	12.2	13.3	13.2	15.3	15.8	18.1
	20	5.1	6.8	6.9	9.3	9.6	11.4	11.7	12.9	13.2	15.4	15.3	17.3
2	4	5.1	6.7	6.8	9.2	9.5	11.3	11.6	12.7	12.8	14.7	14.8	16.7
	15	5.3	7.1	7.5	10.1	11.0	13.1	13.7	15.0	15.0	17.1	17.0	18.9
	17	5.1	6.8	6.8	9.1	9.3	11.1	11.2	12.2	12.1	13.9	14.3	16.0
3	7	4.8	6.2	6.4	8.4	8.7	10.2	10.3	11.2	11.1	12.7	13.1	14.7
	11	5.2	6.9	7.1	9.4	9.7	11.3	11.7	12.7	13.1	14.9	15.2	16.9
	21	5.5	7.3	7.2	9.4	9.5	11.1	11.2	12.1	12.2	13.7	13.7	15.1
4	5	4.9	6.4	6.6	8.6	8.8	10.3	10.4	11.2	11.5	12.9	12.9	14.2
	18	5.3	7.0	7.0	9.2	9.3	10.8	10.8	11.7	11.9	13.3	13.3	14.6
	23	5.7	7.5	7.7	10.0	10.3	11.9	12.0	12.9	13.1	14.6	4.9	16.3
5	9	5.0	6.6	6.6	8.6	8.7	10.0	10.2	10.9	11.1	12.4	12.4	13.7
	24	5.2	6.9	7.0	9.0	9.1	10.5	10.5	11.4	11.5	12.8	12.8	14.1
	27	4.8	6.3	6.4	8.3	8.4	9.8	9.9	10.8	10.8	12.3	12.6	14.1
6	1	5.3	7.0	7.1	9.2	9.3	10.7	10.8	11.7	11.9	13.4	13.6	15.1
	2	5.1	6.7	6.8	8.9	8.9	10.4	10.5	11.4	11.7	13.3	13.5	15.2
	25	5.2	7.0	7.1	9.2	9.6	11.1	11.3	12.3	12.5	14.2	14.5	16.0
7	12	5.2	6.8	6.8	8.7	8.7	9.9	10.0	10.6	10.7	11.9	11.9	13.3
	14	5.4	7.1	7.1	9.2	9.2	10.5	10.6	11.3	11.4	12.6	12.8	13.9
	19	5.3	6.9	6.9	8.8	8.9	10.1	10.2	11.0	11.1	12.4	12.3	13.4
8	6	5.0	6.6	6.6	8.5	8.5	9.7	9.8	10.4	10.5	11.7	11.9	13.3
	13	5.3	7.0	7.0	8.9	9.0	10.2	10.2	11.0	11.0	12.2	12.2	13.5
	16	5.4	7.2	7.2	9.2	9.2	10.6	10.6	11.3	11.4	12.7	12.9	14.3
Control	10	3.6	4.2	4.2	5.3	5.3	6.1	6.1	6.5	6.5	7.4	7.4	8.3
	22	4.2	5.1	5.1	6.4	6.4	7.2	7.2	8.0	8.0	8.9	8.9	9.9
	26	3.6	4.4	4.4	5.6	5.6	6.5	6.5	7.2	7.2	8.3	8.3	9.2

Table 10—Basal area per acre (square feet) of all live trees, by treatment, plot, treatment period, year, and stand age (years)

		Calibration		1st period		2d period		3d period		4th period		5th period	
Treatment	Plot no.	Start (1963, 20)	End (1966, 23)	Start (1966, 23)	End (1970, 27)	Start (1970, 27)	End (1973, 30)	Start (1973, 30)	End (1975, 32)	Start (1975, 32)	End (1979, 36)	Start (1979, 36)	End (1983, 40)
1	3	49.6	88.4	55.9	102.1	60.3	86.0	64.7	77.7	65.5	88.8	68.6	88.3
	8	50.2	84.2	54.8	98.1	60.3	84.2	64.5	76.7	66.3	89.4	68.3	89.5
	20	48.3	84.0	54.8	98.1	60.6	85.2	63.9	76.6	66.5	90.1	70.2	89.6
2	4	50.3	87.3	56.0	102.2	66.1	93.5	77.0	93.0	84.3	112.3	102.0	129.2
	15	50.1	88.3	57.0	102.6	66.1	93.1	77.3	92.3	85.7	111.8	102.0	127.0
	17	49.7	85.8	54.7	96.7	66.4	91.3	75.0	89.0	84.2	110.1	100.6	126.2
3	7	48.6	83.0	65.2	113.1	81.8	112.5	92.3	109.2	97.7	127.3	107.8	135.5
	11	49.3	87.2	65.1	114.5	81.6	111.5	92.7	109.7	97.8	127.9	106.9	132.9
	21	49.1	84.7	62.5	106.8	81.4	109.9	92.2	107.8	97.3	123.4	107.9	130.3
4	5	50.7	88.4	66.9	116.2	86.6	117.8	105.8	124.1	115.3	145.6	140.6	170.5
	18	49.6	85.9	65.6	113.5	87.3	118.0	105.5	122.9	115.9	145.4	140.4	168.8
	23	51.0	85.8	64.4	108.3	87.0	115.7	105.3	122.3	116.3	144.7	139.4	166.1
5	9	48.2	83.5	75.0	126.5	103.0	136.9	121.3	139.2	130.5	163.6	147.4	174.1
	24	50.7	89.9	74.9	124.1	103.4	137.1	121.1	140.7	130.1	160.8	148.4	174.5
	27	48.7	84.5	74.8	128.9	104.5	138.8	120.8	140.6	130.5	168.6	147.8	177.7
6	1	50.2	87.2	75.2	125.9	98.1	131.1	107.9	126.4	112.1	141.6	115.4	143.7
	2	50.5	89.1	75.1	128.2	97.6	132.0	108.2	127.6	111.6	144.7	115.0	145.0
	25	48.8	87.6	75.0	128.1	97.9	131.6	108.9	127.8	111.6	143.0	114.4	140.3
7	12	49.2	83.7	83.7	136.7	124.6	161.0	150.3	169.4	162.3	196.5	185.8	219.0
	14	51.0	88.5	85.5	141.6	124.7	162.9	149.4	169.4	162.3	198.0	186.4	222.5
	19	50.0	85.5	85.5	139.8	124.1	161.0	150.3	170.7	162.3	192.3	186.5	221.7
8	6	51.2	88.8	86.7	141.5	118.8	154.4	137.0	154.9	145.7	179.9	154.7	187.7
	13	51.0	88.1	85.6	137.2	118.6	153.0	136.5	153.9	143.9	175.4	154.4	183.4
	16	49.0	86.6	85.2	139.1	118.6	155.4	137.4	157.9	144.1	180.1	153.7	188.4
Control	10	134.1	178.4	178.4	218.8	218.8	243.5	243.5	250.0	250.0	261.1	261.1	274.6
	22	158.3	201.7	201.7	245.9	245.9	275.4	275.4	277.1	277.1	300.2	300.2	320.2
	26	121.9	174.0	174.0	221.2	221.2	249.9	249.9	255.9	255.9	272.7	272.7	290.5

Table 11—Total stem volume per acre (cubic feet) of all live trees by treatment, plot, treatment period, year, and stand age (years)

Treatment	Plot no.	Calibration Start (1963, 20)	Calibration End (1966, 23)	1st period Start (1966, 23)	1st period End (1970, 27)	2d period Start (1970, 27)	2d period End (1973, 30)	3d period Start (1973, 30)	3d period End (1975, 32)	4th period Start (1975, 32)	4th period End (1979, 36)	5th period Start (1979, 36)	5th period End (1983 40)
1	3	711	1544	985	2262	1347	2246	1693	2138	1806	2830	2191	3118
	8	783	1586	1044	2377	1487	2361	1809	2224	1925	2943	2248	3248
	20	738	1608	1053	2305	1434	2301	1733	2213	1922	2947	2295	3283
2	4	733	1606	1031	2357	1530	2523	2084	2626	2380	3711	3367	4659
	15	745	1727	1135	2473	1631	2639	2206	2810	2610	3739	3410	4691
	17	709	1508	962	2230	1545	2460	2028	2595	2452	3609	3321	4695
3	7	754	1544	1222	2605	1893	3096	2545	3158	2813	4263	3632	5034
	11	754	1605	1200	2714	1937	3080	2567	3187	2853	4252	3559	4843
	21	729	1586	1171	2456	1873	2998	2516	3177	2872	4151	3628	4848
4	5	724	1554	1186	2571	1925	3017	2714	3333	3112	4499	4345	6038
	18	706	1593	1220	2712	2089	3241	2904	3661	3476	4940	4773	6461
	23	818	1723	1305	2704	2185	3398	3092	3857	3669	5155	4964	6378
5	9	761	1644	1481	3150	2570	3883	3446	4262	4004	5647	5093	6748
	24	699	1576	1323	2824	2363	3677	3252	3975	3687	5344	4938	6656
	27	700	1476	1311	2911	2364	3647	3174	4035	3746	5435	4765	6602
6	1	761	1601	1388	2927	2287	3543	2919	3681	3265	4683	3818	5279
	2	717	1571	1329	2873	2193	3449	2830	3556	3124	4671	3718	5275
	25	752	1626	1393	3057	2342	3672	3049	3818	3340	4796	3841	5057
7	12	753	1552	1552	3233	2944	4402	4114	4996	4792	6626	6265	8196
	14	789	1666	1610	3314	2920	4458	4094	4930	4728	6637	6254	8381
	19	708	1503	1503	3257	2896	4348	4067	4952	4716	6423	6227	8670
8	6	755	1607	1572	3231	2718	4184	3730	4462	4208	6084	5233	7080
	13	770	1588	1543	3156	2732	4103	3665	4346	4063	5775	5088	6614
	16	780	1706	1679	3486	2972	4496	3973	4811	4394	6218	5310	7207
Control	10	1823	3204	3204	4942	4942	6269	6269	7002	7002	8298	8298	9542
	22	2344	3787	3787	6019	6019	7843	7843	8529	8529	10521	10521	12533
	26	1780	3094	3094	5272	5272	6753	6753	7325	7325	9116	9116	10533

Table 12—Trees per acre, quadratic mean d.b.h., basal area per acre, total stem volume per acre, and height of the 40 largest trees per acre, by treatment, treatment period, year, and stand age (years)

Treatment number	Calibration		1st period		2d period		3d period		4th period		5th period	
	Start (1963, 20)	End (1966, 23)	Start (1966, 23)	End (1970, 27)	Start (1970, 27)	End (1973, 30)	Start (1973, 30)	End (1975, 32)	Start (1975, 32)	End (1979, 36)	Start (1979, 36)	End (1983, 40),
						Number of trees per acre						
1	353	352	215	215	118	118	83	83	70	70	52	52
2	343	342	207	207	125	123	97	97	90	90	80	80
3	343	342	252	252	175	175	140	140	123	123	102	102
4	333	330	243	243	180	180	160	160	145	145	138	138
5	365	363	312	312	250	248	213	212	193	193	170	165
6	338	338	283	283	210	210	168	168	142	142	110	110
7	328	328	323	323	287	287	262	260	243	238	225	223
8	337	335	327	327	275	275	242	240	222	220	187	183
Control	1727	640	1640	1272	1272	1087	1087	938	938	767	767	653
						Quadratic mean d.b.h. (inches)						
1	5.1	6.7	6.9	9.2	9.7	11.5	11.9	13.0	13.2	15.3	15.7	17.8
2	5.2	6.8	7.0	9.4	9.9	11.7	12.0	13.2	13.1	15.1	15.3	17.1
3	5.1	6.8	6.8	9.0	9.2	10.8	11.0	11.9	12.0	13.7	13.9	15.5
4	5.3	6.9	7.0	9.2	9.4	10.9	11.0	11.9	12.1	13.6	13.6	14.9
5	5.0	6.6	6.6	8.6	8.7	10.1	10.2	11.0	11.1	12.5	12.6	14.0
6	5.2	6.9	7.0	9.1	9.2	10.7	10.9	11.8	12.0	13.6	13.8	15.4
7	5.3	6.9	6.9	8.9	8.9	10.2	10.3	10.9	11.1	12.3	12.3	13.5
8	5.2	6.9	6.9	8.8	8.9	10.1	10.2	10.9	10.9	12.2	12.3	13.7
Control	3.8	4.5	4.5	5.7	5.7	6.6	6.6	7.1	7.1	8.2	8.2	9.1
						Basal area per acre (square feet)						
1	49.4	85.5	55.1	99.4	60.4	85.1	64.4	77.0	66.1	89.4	69.0	89.1
2	50.0	87.1	55.9	100.5	66.2	92.6	76.5	91.4	84.7	111.4	101.5	127.5
3	49.0	85.0	64.2	111.5	81.6	111.3	92.4	108.9	97.6	126.2	4107.5	132.9
4	50.4	86.7	65.6	112.6	87.0	117.2	105.5	123.1	115.8	145.2	140.2	168.5
5	49.2	86.0	74.9	126.5	103.6	137.6	121.1	140.1	130.4	164.3	147.9	175.4
6	49.9	88.0	75.1	127.4	97.8	131.5	108.3	127.3	111.8	143.1	114.9	143.0
7	50.1	85.9	84.9	139.4	124.5	161.6	150.0	169.8	162.3	195.6	186.2	221.1
8	50.4	87.8	85.8	139.3	118.7	154.3	137.0	155.6	144.6	178.5	154.3	186.5
Control	138.1	184.7	184.7	228.6	228.6	256.3	256.3	261.0	261.0	278.0	278.0	295.1

Table 12—Trees per acre, quadratic mean d.b.h., basal area per acre, total stem volume per acre, and height of the 40 largest trees per acre, by treatment, treatment period, year, and stand age (years) (continued)

	Calibration		1st period		2d period		3d period		4th period		5th period	
Treatment number	Start (1963, 20)	End (1966, 23)	Start (1966, 23)	End (1970, 27)	Start (1970, 27)	End (1973, 30)	Start (1973, 30)	End (1975, 32)	Start (1975, 32)	End (1979, 36)	Start (1979, 36)	End (1983, 40)
					Total stem volume per acre (cubic feet)							
1	744	1579	1028	2314	1423	2303	1745	2192	1884	2906	2245	3216
2	729	1614	1043	2353	1568	2541	2106	2677	2481	3686	3366	4682
3	746	1578	1197	2592	1901	3058	2543	3174	2846	4222	3606	4908
4	749	1623	1237	2662	2066	3219	2904	3617	3419	4865	4694	6292
5	720	1565	1371	2962	2432	3736	3291	4091	3812	5475	4932	6669
6	743	1599	1370	2952	2274	3555	2933	3685	3243	4717	3792	5204
7	750	1574	1555	3268	2920	4403	4092	4959	4745	6562	6249	8416
8	768	1634	1598	3291	2807	4261	3789	4540	4221	6026	5210	6967
Control	1982	3362	3362	5411	5411	6955	6955	7619	7619	9312	9312	10869

Mean height (feet) of the 40 largest trees per acre

	1963 20	1966 23	1970 27	1973 30	1975 32	1979 36	1983 40
1	40	50	62	71	75	87	98
2	38	49	63	73	78	89	101
3	39	49	61	73	77	89	99
4	40	51	64	74	79	91	103
5	40	50	62	72	77	89	105
6	40	49	62	72	77	88	99
7	39	49	62	73	78	89	102
8	41	50	64	75	79	88	99
Control	43	53	66	76	81	91	101
All treatments	39.8	49.9	63.1	73.1	78.0	88.9	100.8
Standard deviation	1.3	1.3	1.4	1.5	1.8	1.5	2.3
Coefficient of variation (percent)	3.2	2.6	2.2	2.0	2.3	1.7	2.3

Table 13—Periodic annual and total survivor quadratic mean d.b.h. growth, gross basal area per acre, and total stem volume per acre growth and cumulative gross yield for all trees, by treatment period, year, and stand age (years)

Treatment number	Growth													
	Calibration		1st period		2d period		3d period		4th period		5th period		Total	
	1963-66 (20-23)		1966-70 (23-27)		1970-73 (27-30)		1973-75 (30-32)		1975-79 (32-36)		1979-83 (36-40)		1963-83 (20-40)	
	Quadratic mean d.b.h.													
	Inches	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*
1	0.54	—	0.59	—	0.60	—	0.56	—	0.54	—	0.53	—	12.73	—
2	.56	—	.60	—	.61	—	.57	—	.49	—	.46	—	12.04	—
3	.55	—	.55	—	.52	—	.47	—	.42	—	.39	—	10.43	—
4	.56	—	.55	—	.51	—	.44	—	.36	—	.33	—	9.72	—
5	.54	—	.50	—	.45	—	.40	—	.34	—	.32	—	8.99	—
6	.57	—	.53	—	.49	—	.46	—	.40	—	.40	—	10.26	—
7	.55	—	.49	—	.42	—	.33	—	.29	—	.28	—	8.20	—
8	.57	—	.48	—	.42	—	.34	—	.31	—	.32	—	8.42	—
Control	.22	—	.19	—	.16	—	.12	—	.13	—	.13	—	5.22	—
	Basal area per acre													
	Ft^3	*Percent*	*Ft^3*	*Percent*	*Ft^3*	*Percent*	*Ft^3*	*Percent*	*Ft^3*	*Percent*	*Ft^3*	*Percent*	*Ft^3*	*Percent*
1	12.1	17.9	11.1	14.3	8.2	11.3	6.3	8.9	5.8	7.5	5.0	6.4	161.4	215.4
2	12.4	18.1	11.2	14.3	8.9	11.2	7.5	8.9	6.7	6.8	6.5	5.7	176.1	198.4
3	12.0	18.0	11.8	13.4	9.9	10.3	8.3	8.2	7.2	6.4	6.3	5.3	183.5	186.2
4	12.2	17.8	11.8	13.2	10.1	9.9	8.8	7.7	7.3	5.6	7.1	4.6	189.0	69.0
5	12.3	18.3	12.9	12.8	11.5	9.5	9.8	7.5	8.5	5.8	7.6	4.7	207.0	168.0
6	12.7	18.4	13.1	12.9	11.2	9.8	9.5	8.0	7.8	6.1	7.0	5.4	202.4	182.6
7	11.9	17.6	13.6	12.1	12.4	8.7	10.0	6.3	8.8	4.9	8.8	4.3	218.1	148.8
8	12.6	18.2	13.4	11.9	11.9	8.7	9.4	6.4	8.5	5.3	8.2	4.8	212.5	58.2
Control	16.2	10.1	14.2	6.9	12.3	5.1	8.8	3.4	8.5	3.2	8.0	2.8	226.0	94.6
	Total stem volume per acre													
	Ft^3	*Percent*	*Ft^3*	*Percent*	*Ft^3*	*Percent*	*Ft^3*	*Percent*	*Ft^3*	*Percent*	*Ft^3*	*Percent*	*Ft^3*	*Percent*
1	279	24.0	322	19.3	293	15.8	223	11.4	256	10.7	243	8.9	5445	270.9
2	296	25.2	328	19.3	325	15.8	286	11.9	301	9.8	329	8.2	6266	252.2
3	278	24.0	349	18.4	385	15.5	316	11.0	344	9.7	325	7.6	6695	241.8
4	293	24.7	356	18.3	384	14.5	357	10.9	361	8.7	400	7.3	7215	224.3
5	283	24.8	398	18.4	439	14.3	408	11.1	416	9.0	458	7.9	8068	228.9
6	285	24.4	396	18.3	427	14.7	376	11.4	368	9.3	353	7.8	7357	239.5
7	275	23.6	428	17.8	494	13.5	437	9.7	471	8.3	544	7.4	8954	210.4
8	290	24.1	423	17.3	485	13.7	378	9.1	453	8.8	445	7.3	8363	216.8
Control	469	17.6	573	13.1	583	9.4	498	6.8	549	6.5	510	5.0	10679	160.7
	Cumulative gross yield													
	Cubic feet													
1	1581		2868		3748		4195		5217		6189			
2	1616		2926		3902		4473		5679		6995			
3	1581		2975		4131		4763		6139		7441			
4	1628		3054		4206		4920		6366		7964			
5	1570		3160		4477		5294		6956		8787			
6	1599		3182		4463		5215		6689		8100			
7	1574		3286		4769		5643		7527		9704			
8	1637		3330		4784		5540		7352		9131			
Control	3389		5680		7430		8426		10623		12662			

Table 14—Periodic annual mortality for all trees by treatment, period, year, and stand age (years)

Treatment number	End of period 1966 (23)	1970 (27)	1973 (30)	1975 (32)	1979 (36)	1983 (40)	End of period 1966 (23)	1970 (27)	1973 (30)	1975 (32)	1979 (36)	1983 (40)
	Trees per acre						*Quadratic mean d.b.h. (inches)*					
1	1	0	0	0	0	0	3.5	0	0	0	0	0
2	1	0	1	0	0	0	4.2	0	4.3	0	0	0
3	1	0	0	0	0	0	4.1	0	0	0	0	0
4	1	0	0	0	0	0	4.1	0	0	0	0	0
5	1	0	1	1	0	1	5.4	0	7.6	8.0	0	10.0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	1	1	1	0	0	0	5.2	8.7	5.9
8	1	0	0	1	1	1	5.0	0	0	5.0	4.8	5.9
Control	29	92	62	74	43	28	2.1	2.5	3.0	4.0	4.3	4.9
	Basal area per acre (ft^2)						*Total stem volume per acre (ft^3)*					
1	0.04	0	0	0	0	0	0.6	0	0	0	0	0
2	.05	0	.06	0	0	0	.8	0	1.0	0	0	0
3	.05	0	0	0	0	0	.9	0	0	0	0	0
4	.10	0	0	0	0	0	1.6	0	0	0	0	0
5	.09	0	.18	.29	0	.68	1.4	0	4.6	8.3	0	23.6
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	.12	.51	.08	0	0	0	3.2	16.8	2.5
8	.08	0	0	.11	.05	.16	1.2	0	0	2.6	2.0	5.5
Control	.68	3.18	3.10	6.46	4.29	3.70	8.8	60.6	68.8	166.1	126.0	120.2

Table 15—Live trees cut, by treatment, period, year, and stand age (years)

Treatment number	Start of period 1966 (23)	1970 (27)	1973 (30)	1975 (32)	1979 (36)	Start of period 1966 (23)	1970 (27)	1973 (30)	1975 (32)	1979 (36)
	Trees per acre					*Quadratic mean d.b.h. (inches)*				
1	137	97	35	13	18	6.4	8.6	10.4	12.3	14.3
2	135	82	27	7	10	6.5	8.8	10.5	13.6	13.4
3	90	77	35	17	22	6.5	8.5	10.0	11.1	12.6
4	87	63	20	15	7	6.7	8.6	10.3	9.4	11.8
5	52	62	35	18	23	6.3	8.2	9.3	9.9	11.4
6	55	73	42	27	32	6.6	8.6	10.1	10.3	12.8
7	5	37	25	17	13	6.1	8.6	9.2	9.1	11.4
8	8	52	33	18	33	6.6	8.6	9.8	10.5	11.5
Control	0	0	0	0	0	0	0	0	0	0
	Basal area per acre (ft^2)					*Total stem volume per acre (ft^3)*				
1	30.4	39.1	20.8	10.9	20.4	552	892	558	307	662
2	31.2	34.3	16.2	6.7	9.9	571	785	435	197	320
3	20.7	29.9	18.9	11.3	18.7	381	690	515	328	616
4	21.0	25.7	11.6	7.2	5.1	387	596	315	198	171
5	11.1	22.9	16.5	9.8	16.4	194	529	445	278	543
6	12.9	29.6	23.2	15.5	28.1	229	678	622	442	925
7	1.0	14.9	11.6	7.5	9.4	19	348	311	214	313
8	2.0	20.6	17.3	11.0	24.2	36	484	472	318	816
Control	0	0	0	0	0	0	0	0	0	0

Table 16—Number of live trees per acre, by d.b.h. class, treatment, year, and stand age at the start of the calibration and at the end of the last measured treatment period

	Treatment 1		Treatment 2		Treatment 3		Treatment 4		Treatment 5		Treatment 6		Treatment 7		Treatment 8		Control	
D.b.h. class	Start (1963, 20)	End (1983, 40)	Start (1963, 20)	End (1983, 40)	Start (1963, 20)	End (1983, 40)	Start (1963, 20)	End (1983, 40)	Start (1963, 20)	End (1983, 40)	Start (1963, 20)	End (1983, 40)	Start (1963, 20)	End (1983, 40)	Start (1963, 20)	End (1983, 40)	Start (1963, 20)	End (1983, 40),
Inches																		
2[a]	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	482	0
3	30	0	43	0	43	0	35	0	45	0	32	0	33	0	32	0	470	0
4	122	0	75	0	100	0	78	0	105	0	87	0	75	0	83	0	357	10
5	105	0	122	0	97	0	105	0	118	2	117	0	92	2	110	2	225	60
6	58	0	67	0	68	0	72	0	77	2	62	0	85	2	68	0	113	102
7	35	0	33	0	23	0	38	2	17	5	40	0	33	3	33	5	48	97
8	2	0	3	0	8	0	3	7	3	7	2	2	10	8	8	7	5	85
9	0	0	0	0	3	5	2	3	0	5	0	0	0	7	2	10	2	73
10	0	0	0	0	0	2	0	3	0	7	0	2	0	17	0	10	2	75
11	0	0	0	0	0	2	0	2	0	10	0	3	0	23	0	12	0	47
12	0	0	0	0	0	5	0	7	0	12	0	8	0	17	0	13	2	45
13	0	0	0	8	0	10	0	25	0	27	0	8	0	30	0	25	0	23
14	0	3	0	2	0	12	0	15	0	23	0	7	0	33	0	33	0	10
15	0	5	0	12	0	15	0	15	0	15	0	33	0	35	0	30	0	12
16	0	8	0	15	0	13	0	18	0	25	0	17	0	27	0	18	0	8
17	0	8	0	12	0	22	0	23	0	13	0	12	0	12	0	10	0	3
18	0	12	0	12	0	10	0	12	0	5	0	10	0	8	0	3	0	2
19	0	5	0	12	0	7	0	2	0	8	0	7	0	0	0	5	0	2
20	0	5	0	3	0	0	0	3	0	0	0	2	0	0	0	0	0	0
21	0	3	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
22	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	353	52	343	80	343	102	333	138	365	165	338	110	328	223	337	183	1727	653

[a] The 2-inch class includes trees from 2.6 to 3.5 inches d.b.h., and so forth through all classes.

Appendix 2

Stand Development Tables

Table 17a—Per-acre stand development for treatment 1 (plots 3, 8, and 20)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean SD	Ht40[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		*Ft*	*No.*	*In*	*Ft²*	*Ft³*	*No.*	*In*	*Ft²*	- - *Ft³* - -			*No.*	*In*	*Ft²*	- - - *Ft³* - - -			*In*	*Ft²*	*Ft³*	
1963	20	Mean[d]	40	353	5.1	49.4	744	0	0	0	0	0	0	0	0	0	0	744	744	00	0	0	37
		SD	2	24	.1	1.0	36											36	36	00	0	0	2
1966	23	Mean	50	215	6.9	55.1	1028	137	6.4	30.4	552	4.1	.96	2	3.5	.1	2	1579	1581	.54	12.1	278	69
		SD	1	9	.2	.6	37											33	33	.04	.8	11	1
1970	27	Mean	62	118	9.7	60.4	1423	97	8.6	39.1	892	9.3	.93	0	0	0	0	2866	2868	.59	11.1	322	106
		SD	3	3	.1	.2	70											49	52	.03	.4	10	2
1973	30	Mean	71	83	11.9	64.4	1745	35	10.4	20.8	558	16.2	.91	0	0	0	0	3746	3748	.60	8.2	293	125
		SD	2	3	.2	.4	59											40	43	.03	.3	6	1
1975	32	Mean	75	70	13.2	66.1	1884	13	12.3	10.9	307	23.8	.95	0	0	0	0	4193	4195	.56	6.3	223	131
		SD	1	0	.1	.5	68											25	27	.01	.2	16	1
1979	36	Mean	87	52	15.7	69.0	2245	18	14.3	20.4	662	36.7	.94	0	0	0	0	5216	5217	.54	5.8	256	145
		SD	1	3	.3	1.0	52											23	25	.01	.1	1	1
1983	40	Mean	98	52	17.8	89.1	3216	0	0	0	0	0	0	0	0	0	0	6187	6189	.53	5.0	243	155
		SD	1	3	.4	.7	87											62	63	.04	.2	10	2

[a] Ht40: Average height of the 40 largest trees per acre (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] All volumes are total stem, inside bark. Total yield: net = standing + thinning. Gross = standing + thinning + mortality. Does not include approximately 1288 cubic feet removed in calibration cut. Volume removed in thinnings 1966-83 = 2971 (48 percent of total gross yield). Volume in mortality = 2 cubic feet (0 percent of total gross yield).
[d] SD: Standard deviation.

Table 17b—Per-hectare stand development for treatment 1 (plots 3, 8, and 20)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean	Ht100[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		*Meters*	*No.*	*Cm*	*M^2*	*M^3*	*No.*	*Cm*	*M^2*	- - - *M^3* - - -			*No.*	*Cm*	*M^2*	- - - *M^3* - - -			*M^2*	- - - *M^3* - - -		
1963	20	Mean	12.2	873	12.9	11.4	52.1	0	0	0	0	0	0	0	0	0	0	52	52	0	0	0	2.6
1966	23	Mean	15.1	531	17.4	12.7	71.9	338	16.2	7.0	38.6	.1	.96	4	8.8	0	.1	111	111	1.37	2.8	19.5	4.8
1970	27	Mean	18.9	292	24.6	13.9	99.6	239	21.9	9.0	62.4	.3	.93	0	0	0	0	201	201	1.50	2.5	22.5	7.4
1973	30	Mean	21.6	206	30.3	14.8	122.1	86	26.5	4.8	39.1	.5	.91	0	0	0	0	262	262	1.54	1.9	20.5	8.7
1975	32	Mean	22.9	173	33.5	15.2	131.9	33	31.2	2.5	21.5	.7	.95	0	0	0	0	294	294	1.42	1.5	15.6	9.2
1979	36	Mean	26.4	128	39.8	15.9	157.1	45	36.3	4.7	46.3	1.0	.94	0	0	0	0	365	365	1.37	1.3	17.9	10.1
1983	40	Mean	29.9	128	45.3	20.5	225.1	0	0	0	0	0	0	0	0	0	0	433	433	1.36	1.2	17.0	10

[a] H100: Average height of the 100 largest trees per hectare (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] Volume: All volumes are total stem, inside bark.
Total yield: Net = standing + thinning; gross = standing + thinning + mortality. Does not include approximately 86.7 cubic meters removed in a calibration cut. Volume removed in thinnings = 207.9 cubic meters (48.0 percent of the total gross yield). Volume in mortality = 0.1 cubic meter (0 percent of the total gross yield).

Table 18a—Per-acre stand development for treatment 2 (plots 4, 15, and 17)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean SD	Ht40[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		*Ft*	*No.*	*In*	*Ft²*	*Ft³*	*No.*	*In*	*Ft²*	-- *Ft³* --			*No.*	*In*	*Ft²*	--- *Ft³* ---			*In*	*Ft²*	*Ft³*	
1963	20	Mean	38	343	5.2	50.0	729	0	0	0	0	0	0	0	0	0	0	729	729	0	0	0	36
		SD[d]	2	18	.1	.3	18											18	18	0	0	0	1
1966	23	Mean	49	207	7.1	55.9	1043	135	6.5	31.2	571	4.2	.95	2	4.2	.2	2	1614	1616	.56	12.4	295	70
		SD	4	19	.4	1.1	87											110	106	.02	.4	31	5
1970	27	Mean	63	125	9.9	66.2	1568	82	8.8	34.3	785	9.6	.93	0	0	0	0	2924	2926	.60	11.2	328	108
		SD	3	22	.9	.2	54											145	142	.04	.6	9	5
1973	30	Mean	73	97	12.2	76.5	2106	27	10.5	16.2	435	16.4	.90	2	4.3	.2	3	3896	3902	.63	8.8	324	130
		SD	3	19	1.4	1.3	91											193	185	.05	.5	17	6
1975	32	Mean	78	90	13.3	84.7	2481	7	13.6	6.7	197	31.1	1.04	0	0	0	0	4468	4473	.57	7.5	286	140
		SD	4	18	1.5	.9	118											210	202	.07	.5	16	7
1979	36	Mean	89	80	15.4	101.5	3366	10	13.4	9.9	320	39.8	.94	0	0	0	0	5674	5679	.49	6.7	301	158
		SD	2	13	1.4	.8	44											224	215	.05	.3	27	6
1983	40	Mean	101	80	17.2	127.5	4682	0	0	0	0	0	0	0	0	0	0	6989	6995	.46	6.5	329	175
		SD[d]	2	13	1.5	1.6	20											173	164	.03	.3	13	4

[a] Ht40: Average height of the 40 largest trees per acre (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] All volumes are total stem, inside bark. Total yield: net = standing + thinning. Gross = standing + thinning + mortality. Does not include approximately 1253 cubic feet removed in calibration cut. Volume removed in thinnings = 2308 (48 percent of total gross yield). Volume in mortality = 5 cubic feet (0 percent of total gross yield).
[d] SD: Standard deviation.

Table 18b—Per-hectare stand development for treatment 2 (plots 4, 15, and 17)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean	Ht100[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		*Meters*	*No.*	*Cm*	M^2	M^3	*No.*	*Cm*	M^2	--- M^3 ---			*No.*	*Cm*	M^2	-- M^3 --		-- M^2 --		--- M^3 ---		
1963	20	Mean	11.7	848	13.2	11.5	51.0	0	0	0	0	0	0	0	0	0	0	51	51	0	0	0	2.6
1966	23	Mean	14.8	510	18.0	12.9	73.0	333	16.6	7.2	40.0	.1	.95	4	10.7	0	.2	113	113	1.42	2.8	20.6	4.9
1970	27	Mean	19.2	309	25.3	15.2	109.8	202	22.3	7.9	54.9	.3	.93	0	0	0	0	205	205	1.53	2.6	22.9	7.6
1973	30	Mean	22.3	239	31.0	17.6	147.4	66	26.8	3.7	30.5	.5	.90	4	10.9	0	.2	273	273	1.60	2.0	22.7	9.1
1975	32	Mean	23.9	222	33.8	19.5	173.6	16	34.5	1.5	13.8	.9	1.04	0	0	0	0	313	313	1.45	1.7	20.0	9.8
1979	36	Mean	27.2	198	39.1	23.4	235.6	25	34.2	2.3	22.4	1.1	.94	0	0	0	0	397	398	1.24	1.5	21.1	11.0
1983	40	Mean	30.7	198	43.8	29.3	327.7	0	0	0	0	0	0	0	0	0	0	489	490	1.17	1.5	23.0	12.2

[a] H100: Average height of the 100 largest trees per hectare (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] Volume: All volumes are total stem, inside bark.
Total yield: Net = standing + thinning; gross = standing + thinning + mortality. Does not include approximately 87.7 cubic meters removed in a calibration cut. Volume removed in thinnings = 161.5 cubic meters (33.0 percent of the total gross yield).
Volume in mortality = 0.4 cubic meter (0.1 percent of the total gross yield).

Table 19a—Per-acre stand development for treatment 3 (plots 7, 11, and 21)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean SD	Ht40[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		*Ft*	*No.*	*In*	Ft^2	Ft^3	*No.*	*In*	Ft^2	-- Ft^3 --			*No.*	*In*	Ft^2	--- Ft^3 ---			*In*	Ft^2	Ft^3	
1963	20	Mean	39	343	5.1	49.0	746	0	0	0	0	0	0	0	0	0	0	746	746	0	0	0	37
		SD[d]	1	45	.3	.3	15											15	15	0	0	0	1
1966	23	Mean	49	252	6.9	64.2	1197	90	6.5	20.7	381	4.3	.96	2	4.1	.2	3	1578	1581	.55	12.0	78	69
		SD	2	39	.5	1.5	25											31	32	.05	.6	12	1
1970	27	Mean	61	175	9.3	81.6	1901	77	8.5	29.9	690	9.3	.94	0	0	0	0	2972	2975	.55	11.8	349	110
		SD	1	22	.5	.2	33											130	127	.04	.7	29	5
1973	30	Mean	73	140	11.0	92.4	2543	35	10.0	18.9	515	14.8	.92	0	0	0	0	4129	4131	.52	9.9	385	138
		SD	0	18	.7	.2	26											133	129	.02	.4	14	4
1975	32	Mean	77	123	12.1	97.6	2846	17	11.1	11.3	328	20.0	.94	0	0	0	0	4760	4763	.47	8.3	316	149
		SD	1	20	1.0	.2	30											113	110	.04	.4	13	4
1979	36	Mean	89	102	14.0	107.5	3606	22	12.6	18.7	616	30.2	.93	0	0	0	0	6136	6139	.42	7.2	344	170
		SD	0	15	1.1	.6	41											179	175	.05	.6	22	5
1983	40	Mean	99	102	15.6	132.9	4908	0	0	0	0	0	0	0	0	0	0	7438	7441	.39	6.3	325	186
		SD[d]	1	15	1.2	2.6	109											245	241	.05	.7	23	6

[a] Ht40: Average height of the 40 largest trees per acre (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] All volumes are total stem, inside bark.
Total yield: net = standing + thinning. Gross = standing + thinning + mortality.
Does not include approximately 1236 cubic feet removed in calibration cut.
Volume removed in thinnings 1966-83 = 2530 (34 percent of total gross yield).
Volume in mortality 1966-83 = 3 cubic feet (0 percent of total gross yield).
[d] SD: Standard deviation.

Table 19b—Per-hectare stand development for treatment 3 (plots 7, 11, and 21)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean	Ht100[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		Meters	No.	Cm	M^2	M^3	No.	Cm	M^2	- - - M^3 - - -			No.	Cm.	M^2	- - - M^3 - - -			M^2	- - - M^3 - - -		
1963	20	Mean	11.8	848	13.1	11.3	52.2	0	0	0	0	0	0	0	0	0	0	52	52	0	0	0	2.6
1966	23	Mean	14.9	622	17.5	14.8	83.8	222	16.5	4.8	26.7	.1	.96	4	10.4	0	.2	110	111	1.40	2.8	19.4	4.8
1970	27	Mean	18.7	432	23.6	18.8	133.1	189	21.5	6.9	48.3	.3	.94	0	0	0	0	208	208	1.39	2.7	24.4	7.7
1973	30	Mean	22.1	346	28.1	21.2	178.0	86	25.3	4.3	36.0	.4	.92	0	0	0	0	289	289	1.32	2.3	27.0	9.6
1975	32	Mean	23.6	305	30.8	22.4	199.2	41	28.3	2.6	23.0	.6	.94	0	0	0	0	333	333	1.20	1.9	22.1	10.4
1979	36	Mean	27.2	251	35.6	24.7	252.4	54	32.0	4.3	43.1	.9	.93	0	0	0	0	430	430	1.06	1.6	24.1	11.9
1983	40	Mean	30.2	251	39.6	30.6	343.6	0	0	0	0	0	0	0	0	0	0	521	521	1.00	1.5	22.8	13.

[a] H100: Average height of the 100 largest trees per hectare (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] Volume: All volumes are total stem, inside bark.
Total yield: Net = standing + thinning; gross = standing + thinning + mortality. Does not include approximately 86.5 cubic meters removed in a calibration cut. Volume removed in thinnings = 177.1 cubic meters (34.0 percent of the total gross yield). Volume in mortality = 0.2 cubic meter (0 percent of the total gross yield).

Table 20a—Per-acre stand development for treatment 4 (plots 5, 18, and 23)

Year	Stand age	Mean SD	After thinning: Ht40[a] largest	After thinning: Trees left	After thinning: Avg d.b.h.	After thinning: Basal area	After thinning: Total vol.	Removed in thinning: Trees cut	Removed in thinning: Avg d.b.h.	Removed in thinning: Basal area	Removed in thinning: Total vol.	Removed in thinning: Avg vol.	Removed in thinning: Avg d/D[b]	Mortality: Trees dead	Mortality: Avg d.b.h.	Mortality: Basal area	Mortality: Total vol.	Yield[c]: Net vol.	Yield[c]: Gross vol.	Net growth: DBH PAI	Net growth: BA PAI	Net growth: Vol. PAI	Net growth: Vol. MAI
	Yr		Ft	No.	In	Ft^2	Ft^3	No.	In	Ft^2	- - - Ft^3	- - -		No.	In	Ft^2	- - - Ft^3	- - -		In	Ft^2	Ft^3	
1963	20	Mean	40	333	5.3	50.4	749	0	0	0	0	0	0	0	0	0	0	749	749	0	0	0	37
		SDd	2	51	.4	.7	60											60	60	0	0	0	3
1966	23	Mean	51	243	7.1	65.6	1237	87	6.7	21.0	387	4.6	.96	3	4.1	.3	5	1623	1628	.56	12.1	291	71
		SD	3	43	.6	1.3	61											88	96	.04	.5	13	4
1970	27	Mean	64	180	9.5	87.0	2066	63	8.6	25.7	596	9.6	.94	0	0	0	0	3049	3054	.55	11.8	356	113
		SD	4	28	.8	.4	131											97	103	.02	.7	15	4
1973	30	Mean	74	160	11.1	105.5	2904	20	10.3	11.6	315	16.4	.95	0	0	0	0	4201	4206	.51	10.1	384	140
		SD	5	23	.8	.2	189											155	162	.02	.4	20	5
1975	32	Mean	79	145	12.2	115.8	3419	15	9.4	7.2	198	14.1	.80	0	0	0	0	4915	4920	.44	8.8	357	154
		SD	6	18	.8	.5	283											235	241	.02	.3	41	7
1979	36	Mean	91	138	13.7	140.2	4694	7	11.8	5.1	171	27.8	.91	0	0	0	0	6361	6366	.36	7.3	361	177
		SD	5	21	1.1	.6	317											287	293	.01	.2	13	8
1983	40	Mean	103	138	15.0	168.5	6292	0	0	0	0	0	0	0	0	0	0	7959	7964	.33	7.1	400	199
		SD[d]	6	21	1.1	2.2	224											211	212	.01	.4	40	5

[a] Ht40: Average height of the 40 largest trees per acre (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] All volumes are total stem, inside bark.
Total yield: net = standing + thinning. Gross = standing + thinning + mortality.
Does not include approximately 1233 cubic feet removed in calibration cut.
Volume removed in thinnings 1966-83 = 1667 (21 percent of total gross yield).
Volume in mortality 1966-83 = 3 cubic feet (0 percent of total gross yield).
[d] SD: Standard deviation.

Table 20b—Per-hectare stand development for treatment 4 (plots 5, 18, and 23)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean	Ht100[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		*Meters*	*No.*	*Cm*	M^2	M^3	*No.*	*Cm*	M^2	- - - M^3 - - -			*No.*	*Cm.*	M^2	- - - M^3 - - -			M^2	- - - M^3 - - -		
1963	20	Mean	12.1	823	13.5	11.6	52.5	0	0	0	0	0	0	0	0	0	0	52	52	0	0	0	2.6
1966	23	Mean	15.5	601	18.0	15.1	86.6	214	17.0	4.8	27.1	.1	.96	8	10.4	.1	.3	114	114	1.43	2.8	20.4	4.9
1970	27	Mean	19.5	445	24.1	20.0	144.6	156	21.9	5.9	41.7	.3	.94	0	0	0	0	213	214	1.39	2.7	24.9	7.9
1973	30	Mean	22.6	395	28.1	24.3	203.2	49	26.3	2.7	22.0	.5	.95	0	0	0	0	294	294	1.29	2.3	26.9	9.8
1975	32	Mean	24.2	358	30.9	26.6	239.3	37	23.9	1.7	13.9	.4	.80	0	0	0	0	344	344	1.12	2.0	25.0	10.8
1979	36	Mean	27.7	342	34.9	32.2	328.6	16	30.0	1.2	12.0	.8	.91	0	0	0	0	445	446	.92	1.7	25.3	12.4
1983	40	Mean	31.5	342	38.2	38.8	440.5	0	0	0	0	0	0	0	0	0	0	557	558	.84	1.6	28.0	13.9

[a] H100: Average height of the 100 largest trees per hectare (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] Volume: All volumes are total stem, inside bark. Total yield: Net = standing + thinning; gross = standing + thinning + mortality. Does not include approximately 86.3 cubic meters removed in a calibration cut. Volume removed in thinnings = 116.7 cubic meters (20.9 percent of the total gross yield). Volume in mortality = 0.3 cubic meter (0.1 percent of the total gross yield).

Table 21a—Per-acre stand development for treatment 5 (plots 9, 24, and 27)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean SD	Ht40[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		*Ft*	*No.*	*In*	*Ft²*	*Ft³*	*No.*	*In*	*Ft²*	- - - *Ft³* - - -			*No.*	*In*	*Ft²*	- - - *Ft³* - - -			*In*	*Ft²*	- - *Ft³* - -	
1963	20	Mean	40	365	5.0	49.2	720	0	0	0	0	0	0	0	0	0	0	720	720	0	0	0	36
		SD[d]	1	26	.2	1.3	35											35	35	0	0	0	2
1966	23	Mean	50	312	6.7	74.9	1371	52	6.3	11.1	194	3.8	.95	2	5.4	.3	4	1565	1570	.54	12.3	282	68
		SD	2	30	.3	.1	95											84	78	.03	.7	20	4
1970	27	Mean	62	250	8.7	103.6	2432	62	8.2	22.9	529	8.7	.96	0	0	0	0	3155	3160	.50	12.9	398	117
		SD	2	20	.3	.8	119											136	133	0	.6	21	5
1973	30	Mean	72	213	10.2	121.1	3291	35	9.3	16.5	445	12.8	.93	2	7.6	.5	14	4459	4477	.45	11.3	434	149
		SD	4	13	.3	.2	140											145	129	.01	.1	6	5
1975	32	Mean	77	193	11.1	130.4	3812	18	9.9	9.8	278	15.5	.90	2	8.0	.6	17	5259	5294	.41	9.5	400	164
		SD	3	13	.4	.2	169											167	166	.04	.5	35	5
1979	36	Mean	89	170	12.6	147.9	4932	23	11.4	16.4	543	24.6	.93	0	0	0	0	6922	6956	.34	8.5	416	192
		SD	4	5	.2	.5	164											157	164	.03	1.0	6	4
1983	40	Mean	105	165	14.0	175.4	6669	0	0	0	0	0	0	5	10.0	2.7	95	8658	8787	.33	6.9	434	216
		SD[d]	1	5	.2	1.9	74											146	239	.02	.5	23	4

[a] Ht40: Average height of the 40 largest trees per acre (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] All volumes are total stem, inside bark.
Total yield: net = standing + thinning. Gross = standing + thinning + mortality.
Does not include approximately 1262 cubic feet removed in calibration cut.
Volume removed in thinnings 1966-83 = 1990 (23 percent of total gross yield).
Volume in mortality 1966-83 = 129 cubic feet (1 percent of total gross yield).
[d] SD: Standard deviation.

Table 21b—Per-hectare stand development for treatment 5 (plots 9, 24, and 27)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean	Ht40[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		Meters	No.	Cm	M^2	M^3	No.	Cm	M^2	--- M^3 ---			No.	Cm	M^2	--- M^3 ---			M^2	--- M^3 ---		
1963	20	Mean	12.2	902	12.7	11.3	50.4	0	0	0	0	0	0	0	0	0	0	50	50	0	0	0	2.5
1966	23	Mean	15.3	770	16.9	17.2	96.0	128	15.9	2.5	13.6	.1	.95	4	13.8	.1	.3	110	110	1.37	2.8	19.7	4.8
1970	27	Mean	19.0	618	22.2	23.8	170.3	152	21.0	5.3	37.1	.2	.96	0	0	0	0	221	221	1.27	3.0	27.8	8.2
1973	30	Mean	21.9	527	26.0	27.8	230.3	86	23.7	3.8	31.1	.4	.93	4	19.4	.1	1.0	312	313	1.15	2.6	30.4	10.4
1975	32	Mean	23.6	478	28.3	30.0	266.9	45	25.1	2.2	19.5	.4	.90	4	20.4	.1	1.2	368	371	1.04	2.2	28.0	11.5
1979	36	Mean	27.1	420	32.1	34.0	345.3	58	28.9	3.8	38.0	.7	.93	0	0	0	0	485	487	.87	2.0	29.1	13.5
1983	40	Mean	31.9	408	35.5	40.3	466.8	0	0	0	0	0	0	12	25.3	.6	6.6	606	615	.85	1.6	30.4	15.2

a H100: Average height of the 100 largest trees per hectare (estimated from d.b.h. and d.b.h./volume curves).
b d/D: Average d.b.h. cut/average d.b.h. before thinning.
c Volume: All volumes are total stem, inside bark. Total yield: Net = standing + thinning; gross = standing + thinning + mortality.
Does not include approximately 88.4 cubic meters removed in a calibration cut. Volume removed in thinnings = 139.3 cubic meters (22.6 percent of the total gross yield). Volume in mortality = 9.0 cubic meters (1.5 percent of the total gross yield).

Table 22a—Per-acre stand development for treatment 6 (plots 1, 2, and 25)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean SD	Ht40[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		*Ft*	*No.*	*In*	*Ft2*	*Ft3*	*No.*	*In*	*Ft2*	--- *Ft*^{3}	---		*No.*	*In*	*Ft*^{2}	--- *Ft*^{3}	---		*In*	*Ft*^{2}	-- *Ft*^{3}	--
1963	20	Mean	40	338	5.2	49.9	743	0	0	0	0	0	0	0	0	0	0	743	743	0	0	0	37
		SD[d]	2	19	.1	.9	24											24	24	0	0	0	1
1966	23	Mean	49	283	7.0	75.1	1370	55	6.6	12.9	229	4.2	.95	0	0	0	0	1599	1599	.57	12.7	285	70
		SD	2	14	.2	.1	36											27	27	.02	.3	6	1
1970	27	Mean	62	210	9.3	97.8	2274	73	8.6	29.6	678	9.3	.95	0	0	0	0	3182	3182	.53	13.1	396	118
		SD	2	15	.3	.2	75											94	94	.01	.3	18	3
1973	30	Mean	72	168	10.9	108.3	2933	42	10.1	23.2	622	15.0	.94	0	0	0	0	4463	4463	.49	11.2	427	149
		SD	2	13	.4	.5	110											137	137	.02	.2	14	5
1975	32	Mean	77	142	12.0	111.8	3243	27	10.3	15.5	442	16.7	.88	0	0	0	0	5215	5215	.46	9.5	376	163
		SD	1	10	.4	.3	110											154	154	.02	.2	11	5
1979	36	Mean	88	110	13.9	114.9	3792	32	12.8	28.1	925	29.3	.94	0	0	0	0	6689	6689	.40	7.8	368	186
		SD	1	9	.5	.5	65											139	139	.02	.4	16	4
1983	40	Mean	99	110	15.5	143.0	5204	0	0	0	0	0	0	0	0	0	0	8100	8100	.40	7.0	353	203
		SD	1	9	.5	2.5	127											88	88	.02	.5	44	2

[a] Ht40: Average height of the 40 largest trees per acre (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] All volumes are total stem, inside bark.
Total yield: net = standing + thinning. Gross = standing + thinning + mortality.
Does not include approximately 1239 cubic feet removed in calibration cut.
Volume removed in thinnings 1966-83 = 2897 (36 percent of total gross yield).
Volume in mortality 1966-83 = 0 cubic feet (0 percent of total gross yield).
[d] SD: Standard deviation.

Table 22b-Per-hectare stand development for treatment 6 (plots 1, 2, and 25)

			After thinning											Mortality				Yield[c]		Net growth			
Year	Stand age	Mean	Ht40[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		*Meters*	*No.*	*Cm*	*M²*	*M³*	*No.*	*Cm*	*M²*	- - - *M³* - - -			*No.*	*Cm*	*M²*	- - - *M³* - - -			*M²*	- - - *M³* - - -		
1963	20	Mean	12.2	836	13.2	11.5	52.0	0	0	0	0	0	0	0	0	0	0	52	52	0	0	0	2.6
1966	23	Mean	15.0	700	17.7	17.3	95.9	136	16.7	3.0	16.1	.1	.95	0	0	0	0	112	112	1.45	2.9	20.0	4.9
1970	27	Mean	19.0	519	23.5	22.5	159.2	181	21.9	6.8	47.5	.3	.95	0	0	0	0	223	223	1.34	3.0	27.7	8.2
1973	30	Mean	22.0	416	27.7	24.9	205.3	103	25.7	5.3	43.6	.4	.94	0	0	0	0	312	312	1.25	2.6	29.9	10.4
1975	32	Mean	23.5	350	30.6	25.7	227.0	66	26.3	3.6	30.9	.5	.88	0	0	0	0	365	365	1.16	2.2	26.3	11.4
1979	36	Mean	26.8	272	35.3	26.4	265.5	78	32.5	6.5	64.7	.8	.94	0	0	0	0	468	468	1.01	1.8	25.8	13.0
1983	40	Mean	30.1	272	39.3	32.9	364.3	0	0	0	0	0	0	0	0	0	0	567	567	1.01	1.6	24.7	14.2

[a] H100: Average height of the 100 largest trees per hectare (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] Volume: All volumes are total stem, inside bark. Total yield: Net = standing + thinning; gross = standing + thinning + mortality. Does not include approximately 86.7 cubic meters removed in a calibration cut. Volume removed in thinnings = 202.8 cubic meters (35.8 percent of the total gross yield). Volume in mortality = 0 cubic meter (0 percent of the total gross yield).

Table 23a—Per-acre stand development for treatment 7 (plots 12, 14, and 19)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean SD	Ht40[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		Ft	No.	In	Ft^2	Ft^3	No.	In	Ft^2	--- Ft^3 ---			No.	In	Ft^2	--- Ft^3 ---			In	Ft^2	-- Ft^3 --	
1963	20	Mean	39	328	5.3	50.1	750	0	0	0	0	0	0	0	0	0	0	750	750	0	0	0	37
		SD[d]	1	3	.1	.9	41											41	41	0	0	0	2
1966	23	Mean	49	323	6.9	84.9	1555	5	6.1	1.0	19	1.2	.29	0	0	0	0	1574	1574	.55	11.9	275	68
		SD	1	12	.2	1.0	54											83	83	.02	.5	15	4
1970	27	Mean	62	287	8.9	124.5	2920	37	8.6	14.9	348	9.5	.97	0	0	0	0	3286	3286	.49	13.6	428	122
		SD	1	15	.2	.3	24												73	73	.02	.4	9
1973	30	Mean	73	262	10.3	150.0	4092	25	9.2	11.6	311	12.4	.91	0	0	0	0	4769	4769	.42	12.4	494	159
		SD	1	15	.3	.5	24											120	120	.02	.3	16	4
1975	32	Mean	78	243	11.1	162.3	4745	17	9.1	7.5	214	13.0	.84	2	5.2	.2	6	5637	5643	.35	9.9	434	176
		SD	1	15	.3	0	41											93	89	.04	.3	14	3
1979	36	Mean	89	225	12.3	186.2	6249	13	11.4	9.4	313	27.5	.99	5	8.7	2.0	67	7454	7527	.30	8.3	454	207
		SD	1	15	.4	.4	20											180	115	.01	.7	26	5
1983	40	Mean	102	223	13.5	221.1	8416	0	0	0	0	0	0	2	5.9	.3	10	9620	9704	.29	8.7	542	241
		SD	2	13	.4	1.8	239											246	286	.01	.4	65	6

[a] Ht40: Average height of the 40 largest trees per acre (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] All volumes are total stem, inside bark.
Total yield: net = standing + thinning. Gross = standing + thinning + mortality.
Does not include approximately 1232 cubic feet removed in calibration cut.
Volume removed in thinnings 1966-83 = 1205 (12 percent of total gross yield).
Volume in mortality 1966-83 = 84 cubic feet (1 percent of total gross yield).
[d] SD: Standard deviation.

Table 23b—Per-hectare stand development for treatment 7 (plots 12, 14, and 19)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean	Ht100[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		*Meters*	*No.*	*Cm*	M^2	M^3	*No.*	*Cm*	M^2	- - - M^3 - - -			*No.*	*Cm*	M^2	- - - M^3 - - -			M^2	- - - M^3 - - -		
1963	20	Mean	11.8	811	13.4	11.5	52.5	0	0	0	0	0	0	0	0	0	0	52	52	0	0	0	2.6
1966	23	Mean	15.0	799	17.6	19.5	108.9	12	15.5	.2	1.3	0	.29	0	0	0	0	110	110	1.39	2.7	19.2	4.8
1970	27	Mean	19.0	708	22.7	28.6	204.4	91	22.0	3.4	24.3	.3	.97	0	0	0	0	230	230	1.24	3.1	30.0	8.5
1973	30	Mean	22.2	646	26.1	34.5	286.4	62	23.5	2.7	21.8	.4	.91	0	0	0	0	334	334	1.06	2.8	34.6	11.1
1975	32	Mean	23.6	601	28.1	37.3	332.1	41	23.2	1.7	15.0	.4	.84	4	13.2	.1	.4	395	395	.88	2.3	30.4	12.3
1979	36	Mean	27.1	556	31.4	42.8	437.4	33	28.9	2.2	21.9	.8	.99	12	22.0	.5	4.7	522	527	.77	1.9	31.8	14.5
1983	40	Mean	31.1	552	34.3	50.8	589.1	0	0	0	0	0	0	4	15.0	.1	.7	673	679	.73	2.0	37.9	16.8

[a] H100: Average height of the 100 largest trees per hectare (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] Volume: All volumes are total stem, inside bark. Total yield: Net = standing + thinning; gross = standing + thinning + mortality. Does not include approximately 86.3 cubic meters removed in a calibration cut. Volume removed in thinnings = 84.3 cubic meters (12.4 percent of the total gross yield). Volume in mortality = 5.9 cubic meters (0.9 percent of the total gross yield).

Table 24a—Per-acre stand development for treatment 8 (plots 6, 13, and 16)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean SD	Ht40[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		*Ft*	*No.*	*In*	*Ft²*	*Ft³*	*No.*	*In*	*Ft²*	- - - *Ft³* - - -			*No.*	*In*	*Ft²*	- - - *Ft³* - - -			*In*	*Ft²*	- - *Ft³* - -	
1963	20	Mean	41	337	5.3	50.4	768	0	0	0	0	0	0	0	0	0	0	768	768	0	0	0	38
		SD[d]	1	35	.2	1.2	12											12	12	0	0	0	1
1966	23	Mean	50	327	7.0	85.8	1598	8	6.6	2.0	36	4.5	.96	2	5.0	.2	4	1634	1637	.57	12.5	289	71
		SD	1	31	.3	.8	72											63	61	.03	.1	18	3
1970	27	Mean	64	275	8.9	118.7	2807	52	8.6	20.6	484	9.5	.97	0	0	0	0	3327	3330	.48	13.4	423	123
		SD	2	23	.4	.1	143											164	162	.02	.4	25	6
1973	30	Mean	75	242	10.2	137.0	3789	33	9.8	17.3	472	14.5	.97	0	0	0	0	4781	4784	.42	11.9	485	159
		SD	1	18	.4	.4	163											236	235	.03	.4	26	8
1975	32	Mean	79	222	11.0	144.6	4221	18	10.5	11.0	318	17.5	.96	2	5.0	.2	5	5531	5540	.35	9.3	375	173
		SD	2	18	.4	1.0	166											316	308	.04	.8	40	10
1979	36	Mean	88	187	12.3	154.3	5210	33	11.5	24.2	816	24.9	.95	2	4.8	.2	8	7335	7352	.32	8.5	451	204
		SD	3	15	.5	.5	113											366	346	.02	.6	21	10
1983	40	Mean	99	183	13.7	186.5	6967	0	0	0	0	0	0	3	5.9	.6	22	9092	9131	.34	8.1	439	227
		SD[d]	4	13	.5	2.7	312											558	523	.01	.7	50	14

[a] Ht40: Average height of the 40 largest trees per acre (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] All volumes are total stem, inside bark.
Total yield: net = standing + thinning. Gross = standing + thinning + mortality.
Does not include approximately 1214 cubic feet removed in calibration cut.
Volume removed in thinnings 1966-83 = 2125 (23 percent of total gross yield).
Volume in mortality 1966-83 = 29 cubic feet (0 percent of total gross yield).
[d] SD: Standard deviation.

Table 24b—Per-hectare stand development for treatment plots 6, 13, and 16)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean	Ht100[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		*Meters*	*No.*	*Cm*	*M^2*	*M^3*	*No.*	*Cm*	*M^2*	- - - *M^3* - - -			*No.*	*Cm*	*M^2*	- - - *M^3* - - -			*M^2*	- - - *M^3* - - -		
1963	20	Mean	12.4	832	13.4	11.6	53.8	0	0	0	0	0	0	0	0	0	0	54	54	0	0	0	2.7
1966	23	Mean	15.4	807	17.7	19.7	111.9	21	16.8	.5	2.5	.1	.96	4	12.7	.1	.2	114	115	1.44	2.9	20.2	5.0
1970	27	Mean	19.6	679	22.7	27.3	196.5	128	21.7	4.7	33.9	.3	.97	0	0	0	0	233	233	1.21	3.1	29.6	8.6
1973	30	Mean	22.8	597	26.0	31.5	265.2	82	24.8	4.0	33.0	.4	.97	0	0	0	0	335	335	1.06	2.7	33.9	11.2
1975	32	Mean	24.2	548	27.8	33.2	295.5	45	26.7	2.5	22.3	.5	.96	4	12.7	.1	.4	387	388	.90	2.1	26.3	12.1
1979	36	Mean	26.7	461	31.4	35.5	364.7	82	29.3	5.6	57.1	.7	.95	4	12.2	0	.6	513	515	.80	1.9	31.6	14.3
1983	40	Mean	30.3	453	34.8	42.9	487.7	0	0	0	0	0	0	8	15.0	.1	1.5	636	639	.85	1.9	30.7	15.9

[a] H100: Average height of the 100 largest trees per hectare (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] Volume: All volumes are total stem, inside bark. Total yield: Net = standing + thinning; gross = standing + thinning + mortality.
Does not include approximately 85.0 cubic meters removed in a calibration cut. Volume removed in thinnings = 148.8 cubic meters (23.3 percent of the total gross yield). Volume in mortality = 2.7 cubic meters (0.4 percent of the total gross yield).

Table 25a—Per acre stand development for the control (plots 10, 22, and 26).

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean SD	Ht40[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		Ft	No.	In	Ft^2	Ft^3	No.	In	Ft^2	- - - Ft^3 - - -			No.	In	Ft^2	- - - Ft^3 - - -			In	Ft^2	- - Ft^3 - -	
1963	20	Mean	43	1727	3.8	138.1	1982	0	0	0	0	0	0	0	0	0	0	1982	1982	0	0	0	99
		SD[d]	2	142	.4	18.5	314											314	314	0	0	0	16
1966	23	Mean	53	1640	4.6	184.7	3362	0	0	0	0	0	0	87	2.1	2.0	27	3362	3389	.24	15.5	460	146
		SD	3	201	.5	14.9	372											372	393	.04	1.6	21	16
1970	27	Mean	66	1272	5.8	228.6	5411	0	0	0	0	0	0	368	2.5	12.7	242	5411	5680	.30	11.0	512	200
		SD	4	158	.5	15.0	552											552	597	.03	.8	68	20
1973	30	Mean	76	1087	6.6	256.3	6955	0	0	0	0	0	0	185	3.0	9.3	206	6955	7430	.28	9.2	515	232
		SD	4	120	.6	16.9	806											806	857	.01	.8	85	27
1975	32	Mean	81	938	7.2	261.0	7619	0	0	0	0	0	0	148	4.0	12.9	332	7619	8426	.30	2.4	332	238
		SD	3	151	.8	14.3	805											805	1060	.10	1.3	41	25
1979	36	Mean	91	767	8.2	278.0	9312	0	0	0	0	0	0	172	4.3	17.2	504	9312	10623	.25	4.2	423	259
		SD	4	103	.8	20.1	1125											1125	1325	.04	1.5	89	31
1983	40	Mean	101	653	9.1	295.1	10869	0	0	0	0	0	0	113	4.9	14.8	481	10869	12662	.23	4.3	389	272
		SD[d]	6	72	.8	23.2	1524											1524	1785	.01	.8	101	38

[a] Ht40: Average height of the 40 largest trees per acre (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] All volumes are total stem, inside bark.
Total yield: net = standing + thinning. Gross = standing + thinning + mortality.
Volume removed in thinnings 1966-1983 = 0 cubic feet.
Volume in mortality 1966-83 = 1792 cubic feet (14 percent of total gross yield).
[d] SD: Standard deviation.

Table 25b—Per-hectare stand development for the control (plots 10, 22, and 26)

			After thinning					Removed in thinning						Mortality				Yield[c]		Net growth			
Year	Stand age	Mean	Ht100[a] largest	Trees left	Avg d.b.h.	Basal area	Total vol.	Trees cut	Avg d.b.h.	Basal area	Total vol.	Avg vol.	Avg d/D[b]	Trees dead	Avg d.b.h.	Basal area	Total vol.	Net vol.	Gross vol.	DBH PAI	BA PAI	Vol. PAI	Vol. MAI
	Yr		Meters	No.	Cm	M^2	M^3	No.	Cm	M^2	- - - M^3 - - -			No.	Cm	M^2	- - - M^3 - - -			M^2	- - - M^3 - - -		
1963	20	Mean	13.0	4265	9.7	31.8	138.8	0	0	0	0	0	0	0	0	0	0	139	139	0	0	0	6.9
1966	23	Mean	16.1	4051	11.6	42.5	235.3	0	0	0	0	0	0	214	5.3	.5	1.9	235	237	.62	3.6	32.2	10.2
1970	27	Mean	20.1	3141	14.7	52.6	378.8	0	0	0	0	0	0	910	6.4	2.9	17.0	379	398	.77	2.5	35.9	14.0
1973	30	Mean	23.1	2684	16.8	58.9	486.9	0	0	0	0	0	0	457	7.7	2.1	14.5	487	520	.71	2.1	36.0	16.2
1975	32	Mean	24.7	2318	18.3	60.0	533.3	0	0	0	0	0	0	366	10.2	3.0	23.3	533	590	.75	.5	23.2	16.7
1979	36	Mean	27.8	1894	20.8	63.9	651.8	0	0	0	0	0	0	424	10.9	3.9	35.3	652	744	.64	1.0	29.6	18.1
1983	40	Mean	30.8	1614	23.2	67.9	760.8	0	0	0	0	0	0	280	12.4	3.4	33.6	761	886	.60	1.0	27.3	19.0

[a] H100: Average height of the 100 largest trees per hectare (estimated from d.b.h. and d.b.h./volume curves).
[b] d/D: Average d.b.h. cut/average d.b.h. before thinning.
[c] Volume: All volumes are total stem, inside bark. Total yield: Net = standing + thinning; gross = standing + thinning + mortality. Volume in mortality = 125.5 cubic meters (14.2 percent of the total gross yield).

Appendix 3

Miscellaneous Tables

Table 26—Total stem cubic-foot and Scribner board-foot volumes per acre (6-inch top and 16-foot logs) in trees larger than 1.5, 7.5, 9.5, 11.5, 13.5, and 15.5 inches d.b.h., after the calibration (age 20), after the 5th treatment period (age 40), and in total production in standing trees at the end of the 5th treatment period and all thinnings (except the calibration)

Treatment	D.b.h. class	Live stand Age 20	Live stand Age 40	Total production	Live Stand Age 20	Live Stand Age 40	Total production
	Inches	*Cubic feet per acre*			*Board feet per acre*		
1	1.6+	744	3216	6187	169	16265	24867
	7.6+	9	3216	5612	11	16265	24580
	9.6+	0	3216	4957	0	16265	23207
	11.6+	0	3216	4519	0	16265	21762
	13.6+	0	3216	3751	0	16265	18730
	15.6+	0	2855	3102	0	14557	15744
2	1.6+	729	4682	6989	174	23537	29817
	7.6+	19	4682	6551	28	23537	29656
	9.6+	0	4682	5943	0	23537	28401
	11.6+	0	4682	5398	0	23537	26593
	13.6+	0	4423	4719	0	22421	23817
	15.6+	0	3837	3947	0	19638	20191
3	1.6+	746	4908	7438	211	23820	31218
	7.6+	68	4908	6978	120	23820	30983
	9.6+	0	4827	6228	0	23582	29248
	11.6	0	4756	5752	0	23324	27660
	13.6+	0	4267	4733	0	21183	23328
	15.6+	0	3119	3297	0	15745	16614
4	1.6+	749	6296	7959	230	30394	34608
	7.6+	34	6280	7545	65	30384	34332
	9.6+	0	6160	6930	0	30106	32974
	11.6+	0	6060	6452	0	29750	31357
	13.6+	0	5057	5160	0	25390	25830
	15.6+	0	3783	3783	0	19379	19379
5	1.6+	720	6669	8658	124	31381	36929
	7.6+	20	6611	8161	31	31339	36592
	9.6+	0	6457	7569	0	30964	35241
	11.6+	0	6095	6755	0	29637	2414
	13.6+	0	4866	5029	0	24287	25001
	15.6+	0	3201	3201	0	16381	16381
6	1.6+	743	5204	8100	182	25223	34447
	7.6+	10	5204	7761	15	25151	34256
	9.6+	0	5186	7136	0	25120	32826
	11.6+	0	5080	6275	0	24735	29931
	13.6+	0	4568	5164	0	22535	25287
	15.6+	0	2824	3057	0	14267	15381
7	1.6+	750	8516	9720	210	38608	42183
	7.6+	54	8365	9381	79	38574	41983
	9.6+	0	8154	8895	0	38050	40829
	11.6+	0	7253	7615	0	34748	4748
	13.6+	0	5716	5842	0	28006	28586
	15.6+	0	2735	2735	0	13831	13831
8	1.6+	768	6967	9092	255	32011	39030
	7.6+	60	6909	8851	100	31943	38831
	9.6+	0	6669	8113	0	31339	37068
	11.6+	0	6169	7198	0	29587	33869
	13.6+	0	4935	5279	0	24098	25699
	15.6+	0	2167	2313	0	10933	11618
9	1.6+	1980	10869	10869	442	35130	35130
	7.6+	91	8989	8989	231	34044	34044
	9.6+	44	6758	6758	139	28565	28565
	11.6+	27	4119	4119	93	19086	19086
	13.6+	0	1924	1924	0	9567	9567
	15.6+	0	957	957	0	4939	4939

Table 27—Periodic annual increment (PAI) in net total stem cubic-foot volume by treatment and period, for all trees 1.6 inches d.b.h. and larger

Period no.	Treatment period: Age	Treatment period: H40	Fixed treatments: 1	3	5	7	Increasing treatments: 2	4	Decreasing treatments: 6	8	Controls: Net	Gross
	Years	*Feet*	*Cubic feet per acre*									
C	20-23	40-50	278	278	282	275	295	291	285	289	460	469
1	23-27	50-63	322	349	398	428	328	356	396	423	512	573
2	27-30	63-73	293	385	434	494	324	384	427	485	515	583
3	30-32	73-78	223	316	400	434	286	357	376	375	332	498
4	32-36	78-89	256	344	416	454	301	361	368	451	423	549
5	36-40	89-101	243	325	434	542	329	400	203	439	389	510

Table 28—Mean annual increment (MAI) in net total stem cubic-foot volume, by treatment and measurement, for all trees 1.6 inches d.b.h. and larger

Measurement no.	Age	H40	Fixed treatments: 1	3	5	7	Increasing treatments: 2	4	Decreasing treatments: 6	8	Control: Net	Gross
	Years	*Feet*	*Cubic feet per acre*									
1	20	40	37	37	36	37	36	37	37	38	99	99
2	23	50	69	69	68	68	70	71	70	71	146	147
3	27	63	106	110	117	122	108	113	118	123	200	210
4	30	73	125	138	149	159	130	140	149	159	232	248
5	32	78	131	149	164	176	140	154	163	173	238	263
6	36	89	145	170	192	207	158	177	186	204	259	295
7	40	101	155	186	216	241	175	189	203	227	272	317

Appendix 4

The nine cooperative study areas.

Study area	Cooperator
Skykomish and Clemons	Western Forestry Research Department Weyerhaeuser Company Tacoma, Washington
Hoskins	College of Forestry Oregon State University Corvallis, Oregon
Rocky Brook, Stampede Creek, and Iron Creek	USDA Forest Service Pacific Northwest Research Station Portland, Oregon
Francis	Department of Natural Resources State of Washington Olympia, Washington
Sayward Forest and Shawnigan Lake	Forestry Canada Pacific and Yukon Region Victoria, British Columbia

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Results of the Hoskins LOGS study in western Oregon are summarized and management implications discussed through the fifth and final planned treatment period. To age 40 thinnings in this low site I Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stand resulted in large increases in diameter growth with reductions in basal area and volume growth and yield. Growth was strongly related to the level of growing stock. Culmination of cubic-foot mean annual increment does not appear to be near for any of the treatments.

Keywords: Growing stock (-increment/yield, increment) growing stock management, stand density, thinnings, Douglas-fir, *Pseudotsuga menziesii,* western Oregon, Oregon, series—Douglas-fir LOGS.

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